IMPACT OF ARTIFICIAL AERATION ON PHYTOPLANKTON GROWTH AND SEASONAL SUCCESSION IN A EUTROPHIC LAKE

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Veselina Aleksandrova Valkov

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Veselina Aleksandrova Valkov

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

DOCTOR OF PHILOSOPHY

SUPERVISORY COMMITTEE:

Wei Lin
Chair

Marinus Otte

Edward DeKeyser

Bernhardt Saini-Eidukat

Malcolm Butler

Approved:

April 1, 2016
Date

Dr. Eakalak Khan
Department Chair

ABSTRACT

Excessive phytoplankton growth caused by increased loadings of nitrogen (N) and phosphorus (P) is the most visible symptoms of eutrophication. At higher densities phytoplankton creates water quality problems such as offensive taste and odor, impaired aesthetics, depletion of dissolved oxygen (DO), and cyanotoxicity concerns.

Artificial aeration is commonly used to eliminate thermal-stratification, to increase DO levels in lakes and reservoirs, and to control P-release from sediments. This research was conducted to evaluate the impact of aeration on sediment nutrient release, nutrient availability for phytoplankton growth, phytoplankton seasonal succession and Cyanobacterial growth. Water samples for nutrient and phytoplankton analysis were taken from a eutrophic reservoir in North Dakota under aerated and non-aerated conditions, where sediment nutrient release was identified as a major source of N and P. Aeration eliminated thermal stratification and increased DO concentrations throughout water column. When aerated, aerobic condition at the sediment-water interface reduced sediment P-release by nearly 50%. However, phosphorus release due to degradation of organic matter continued and was likely enhanced by increased DO levels. Induced mixing from aeration made nutrients equally distributed in the water column and more available for phytoplankton growth, which led to more phytoplankton growth measured as higher chlorophyll-*a* concentration and phytoplankton biovolume. Results of this study reveal that increased mixing and nutrient availability due to aeration are the major reasons for changes in phytoplankton seasonal succession resulting in favoring growth and shifting growth-periods of diatoms, dinoflagellates, and Cyanobacteria. Seasonal succession of phytoplankton community was also affected by nitrogen limitation in the reservoir. Ability of Cyanobacteria to grow at low N concentrations and low N:P ratios stimulated nitrogen-

fixing cyanobacterial species to bloom and maintained higher cyanobacterial growth. Aeration did not reduce algal and cyanobacterial growth in the reservoir.

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DEDICATION

To my beloved family and friends.

This dissertation is especially dedicated in loving memory of my father Aleksander,

whom I miss every day.

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CHAPTER 1. GENERAL INTRODUCTION

Eutrophication driven by excessive input of nitrogen (N) and phsposphrus (P) is one of the most serious environmental challanges worldwide. Increases of N and P concentrations in many lakes and reservoirs stimulate growth of phytoplankton. Major water quality changes and concerns associated with excessive phytoplankton growth include offensive odor and taste, which affect water quality for various uses, and deterioration of aesthetic appearance of water bodies. Die off and decomposition of phytoplankton results in a large diurnal variation of dissolved oxygen (DO) and even complete depletion of DO (anoxic condition) in water bodies. Hypoxia may cause fish kills and further degrading of the aesthetic and recreational value of water bodies.

Cyanobacteria, also known as blue-green algae, are of special concern because in addition to above mentioned effects, some Cyanobacteria species release a broad range of toxins (cyanotoxins) which are harmful to human and aquatic biota (Chorous, 2001; Downing et al., 2001; Scheffer, 2004; Codd et al., 2005). Excessive growth and bloom of Cyanobacteria are among the most visible symptoms of eutrophication of freshwater ecosystems (Moss et al., 1997; Schindler et al., 2008). Frequent and prolonged Cyanobacteria blooms also are of a great concern for the drinking water supply industry. In 2007, cyanobacteria bloom in Lake Taihu caused the City of Wuxi in China to shut down its water supply (Stone, 2011). In August of 2014, detected cyanotoxins in finished drinking water during the massive Cyanobacteria bloom in Lake Erie caused City of Toledo, Ohio to issue "Do Not Drink" order (EPA, 2015). In both cases, many people were left without tap water supply for days to weeks. In North Central America, many lakes and reservoirs become eutrophic. According to the "North Dakota 2012 Integrated Section 305(b) Water Quality Assessment Report" of 2012, 87 out of 253 assessed lakes/reservoirs in North

Dakota are classified as eutrophic, and 29 of them were classified as hypereutrophic (NDDoH, 2012).

Artificial aeration is a common technique used to eliminate thermal stratification and to increase DO in eutrophic lakes (DeMoyer et al., 2003; Gafsi et al., 2009). In artificial aeration, compressed air is released from perforated pipes or diffusers installed on the bottom of a lake or reservoir. Released air mixes hypolimnetic cold water with epilimnetic warm water eliminating thermal stratification. Elimination of stratification enables better vertical circulation (mixing) of water and improves diffusion of the oxygen from oxygenated surface to the bottom layers of water body (DeMoyer et al., 2003). Increase of DO near lake and reservoir bottoms may also result in reduction of phosphorus release from sediment, therefore, reducing phytoplankton growth and its adverse effects.

This study was carried out in the Heinrich-Martin Dam (HMD) Impoundment, a small recreational reservoir in North Dakota that became highly eutrophic due to agricultural runoff. HMD experienced summer thermal stratification, low DO concentrations in the hypolimnion, along with frequent algal blooms, and occasional fish kills. Artificial aeration was installed with the intention to prevent thermal stratification and formation of anaerobic condition on the bottom of reservoir and thereby increasing available habitat for fish (Kratz, 2009). Previous research conducted in 2008 to evaluate the effectiveness of artificial aeration, suggested that the artificial aeration increased DO concentrations and prevented anoxic conditions near the bottom of the reservoir (Overmoe, 2008). Visual, qualitative observations suggested that high phytoplankton growth continued in the reservoir, but samples for phytoplankton biomass and speciation analyses were not taken.

The current research was conducted to evaluate the impact of artificial aeration on nutrient release from sediments, phosphorus balance in the study reservoir, and impact of

changes in nutrient concentrations on phytoplankton growth and phytoplankton community structure.

1.1. Research Questions, Hypotheses, and Objectives

1.1.1. Research questions

- How would artificial aeration affect sediment nutrients release and growth of phytoplankton?
- How would changes in nutrient level and mixing condition affect phytoplankton growth, species seasonal variations, and diversity?
- How would nutrient balance and changes in nutrient availabilities due to artificial aeration affect Cyanobacteria growth?

1.1.2. Hypotheses

- **Hypothesis 1**: Increase of DO on the sediment-water interface, due to artificial aeration, would be effective in preventing metal-bound P. However, artificial aeration would have minimal or negative impact on biological P release from sediments. The biological P release would continue and a significant amount of P will be released from sediments under aerobic conditions.
- **Hypothesis 2**: Change in mixing condition and sediment nutrients release, due to aeration, will change typical phytoplankton seasonal variation in species composition and diversity in phytoplankton population.
- **Hypothesis 3**: The Heinrich-Martin Dam is a eutrophic reservoir with low N:P ratio and naturally stratified in summer. It is well known that low N:P ratio may favor Cyanobacteria growth. Cyanobacteria have the ability to grow under low N concentrations, because some species can fix nitrogen from the atmosphere, which gives an advantage over other phytoplankton species. In addition, most of

Cyanobacteria can control buoyancy, which enable them to migrate throughout the water column to acquire nutrient from the bottom or light in the surface layers in the lake. It expected aeration would change nutrient concentrations and mixing in the reservoir, thereby benefit growth of other phytoplankton species and reduce Cyanobacteria population.

1.2. Research Objectives

The three main goals of this study were to evaluate the effects of artificial aeration on 1) sediment nutrient release, 2) phytoplankton seasonal succession and diversity, and 3) cyanobacterial growth. These goals were accomplished by:

- conducting a comprehensive literature review to gain knowledge and to provide critical analyses of subjects related to this dissertation research in order to identify the gaps and limitations in the published research and to provide the basis, needs, and importance of this research;
- monitoring water quality parameters at sampling sites in the study reservoir to determine seasonal variations and changes caused by artificial aeration, and mixing under aerated and non-aerated conditions;
- collecting and analyzing nutrients (N and P) samples to determine seasonal and spatial variations of nutrients concentrations under both aerated and non-aerated conditions;
- analyzing nutrients data to study phosphorus balance under both aerated and non-aerated conditions;
- collecting and analyzing samples to determine effect of artificial aeration on seasonal variation of Chlorophyll-*a* (Chl-*a*) and phytoplankton species, phytoplankton diversity, and their spatial distributions; and

- determining the effect of mixing and change in nutrient concentrations on Cyanobacterial growth

1.3. Dissertation Organization

The dissertation is organized into three papers prefaced by a general introduction and literature review and followed by the general conclusions and appendices. Chapter 1 is the general introduction that includes the background of this current study, research questions and hypothesis, and dissertation organization.

In CHAPTER 2, a review of relevant literature was conducted to identify gaps and limitations in published studies and to provide the basis of the current study, and to justify the needs and importance of this dissertation research. CHAPTER 3 includes detailed description of the study site and sampling locations as well as sampling duration, frequency and methods used in this study. CHAPTER 4 contains the methods used to analyze 1) chemical (nitrogen and phosphorus), 2) biological (phytoplankton) parameters, and 3) monitoring of field parameters such as water temperature, dissolved oxygen and conductivity. CHAPTER 4 also focuses on the effect of artificial aeration on nutrient concentrations and distributions, nutrient release (flux) from the sediments and nutrient availability for the phytoplankton growth. Furthermore, impacts of aeration on water temperature, DO, and conductivity also were discussed in CHAPTER 4. CHAPTER 5 covers detailed analyses of variations of phytoplankton genera in space (vertical and horizontal) and time, under aerated and non-aerated condition. The analyses include identification and quantification of phytoplankton species, and biovolume determination using the image analysis procedures developed in this study. Phytoplankton biovolume variations were used to determine the effect of artificial aeration on the seasonal variation and diversity of phytoplankton population in the reservoir studied. CHAPTHER 6 is focused on the effect of

aeration and mixing on Cyanobacteria growth and depth distribution, and analyzing the effect of change in nutrient concentrations on Cyanobacteria growth. CHAPTER 7 includes general conclusions and suggestions for future work. Detailed procedures for depth-weighted average, phytoplankton counting, and biovolume determination, as well as all row data and statistical analyses tables are organized in separate appendices.

CHAPTER 2. LITERATURE REVIEW

A literature review was conducted to provide critical analyses of subjects related to this dissertation research in order to identify the gaps and limitations in the published research and to provide basis, needs, and importance of this research study.

2.1. Eutrophication: Definition, Causes, and Effects

Eutrophication is the term used to describe the aging process of aquatic ecosystems with time. Eutrophication is a process of gradual increase of nitrogen (N) and phosphorus (P) concentrations in lakes and reservoirs with time. Eutrophication makes lakes and reservoirs become more productive with plant and animal life while they are slowly filled with remains of aquatic life and may eventually become a pond, then a marsh (Wetzel, 1983). Naturally, eutrophication is a slow process. Human activities (due to rapid urbanization, industrialization, and increasing agricultural production) have increased the nutrient input rate in water bodies and accelerated eutrophication (Burkholder, 2000). Therefore, the term cultural eutrophication has been often used to describe the accelerated increase of nutrient concentrations and increased frequency of phytoplankton blooms in lakes and reservoirs due to human activities. Increases of N and P concentrations in many lakes and reservoirs stimulate growth of aquatic plants including phytoplankton. Excessive growth of phytoplankton in turn causes reduction in water quality in the lakes and reservoirs. Thereafter, eutrophication is one of the most serious environmental challanges worldwide. Major water quality changes related to enhanced phytoplankton growth include a decrease of water transparency, shifts of phytoplankton composition to certain classes, such as Cyanobacteria, and change in dissolved oxygen (DO) concentrations.

Decrease of water column transparency causes low photosynthetic activity for deeper aquatic plants (Sand-Jensen & Burum, 1991; Rohde et al., 2008). The reduced transparency also reduces the recreational value of lakes, particularly for swimming and

boating. Higher phytoplankton biomass may increase water temperature through absorption of light by the phytoplankton cells (Kahru et al., 1993; Ibelings et al., 2003). Higher temperature increases biochemical and chemical reactions in lakes and lowers the solubility of oxygen (Jensen & Andersen, 1992; Gächter & Meyer, 1993; Søndergaard, 2007; Liu et al., 2009; Wu et al., 2011). Increased decomposition of organic matter results in higher release rates of N (Kadlec & Reddy, 2001) and P (Boström et al., 1982; Gomez et al., 1998). Higher mineralization rate, in addition to a lower solubility of DO at higher temperatures, may result in a higher oxygen demand and a severe DO deficit in bottom layers of lakes and reservoirs (Hupfer & Lewandowski, 2008).

A large portion of sediment organic matter is from dead phytoplankton that settles to the bottom during and after growing seasons. Decomposition of organic matter and respiration of organisms contribute to DO depletion in the water column and even establishment of anoxic condition on the sediment-water interface. Low DO could stress fish and even cause fish kill (Chellappa et al., 2008), and lead to loss of suitable habitats for submerged vascular plants and other aquatic biota (Wall et al., 2012). The common consequences related to biomass decomposition and anoxic condition are offensive "sewage-like" odor and poor taste of water, which has a negative impact on water quality and adverse effects on beneficial uses of lakes and reservoirs such as recreation, irrigation, drinking water supply, fishing and swimming. Moreover, change in DO concentrations in the bottom of the water bodies affects microbial metabolism and nutrient cycles (Smith & Schindler, 2009).

In addition to the effects of eutrophication described above, another common symptom associated with eutrophic lakes is shifts in phytoplankton community composition and frequent blooms of Cyanobacteria (Oliver & Ganf, 2000; Paerl & Huisman, 2008; Schindler et al., 2008; Smith & Schindler, 2009). Cyanobacteria have been recognized as a

worldwide challenge. They are often called “noxious” species and their blooms are classified as harmful algal blooms (HAB’s), because of ecosystem changes that they pose and their potential toxicity. The foul smelling surface slimy scum of extreme high cell density that Cyanobacteria form during calm days is unattractive and can remain unchanged for weeks along shores, which results in unfavorable conditions for recreation (Chorus & Bartram, 1999). Some Cyanobacteria species produce a suite of toxins, known as cyanotoxins, which include neurotoxins (affect the nervous system), hepatotoxins (affect liver), and dermatotoxins (affect skin). Cyanotoxines are harmful to humans and other aquatic wildlife (Chorus, 2001; Downing et al., 2001; Scheffer, 2004; Codd et al., 2005). Cyanotoxins in lakes and reservoirs used for recreation and drinking water supply purposes can cause acute and short-term toxic effects that includes fever, headaches, muscle pain, stomach cramps, diarrhea, vomiting, and allergic reactions (EPA, 2012).

2.2. Nutrient (N and P) Cycles in Lakes and Reservoirs

Management of lake and reservoir water quality to reduce the consequences of eutrophication has been mainly focused on reduction of nutrient loading to water bodies. Control of nutrient input, however, requires an understanding of nutrient cycles in lakes and reservoirs.

2.2.1. Nitrogen cycle

A nitrogen cycle (N-cycle) in lakes and reservoirs is presented in Figure 1. Nitrogen may be added to a surface water body, such as a lake or a reservoir, from different sources. Although dry precipitation has been a concern of nitrogen contamination in industrialized areas, the majority of N enters a lake through continuous stream inflows or runoff from precipitation events. The major sources of N include agriculture runoff (fertilizers), storm water runoff from urban areas, industrial discharges, and wastewater effluents. Nitrogen enters water bodies in several forms, including inorganic and organic nitrogen. The primary

inorganic forms of N are ammonia-nitrogen (NH_3-N), nitrate-nitrogen (NO_3^--N), and nitrite-nitrogen (NO_2^--N). These inorganic nitrogen species can be used directly by microorganisms and aquatic plants as growth nutrients. These inorganic forms are collectively called total dissolved inorganic nitrogen (TDIN). Organic N occurs in soluble and particulate forms. Organic-N is found in proteins, amino acids, urea, living or dead organisms (phytoplankton and bacteria), and decaying plant material. Soluble organic-N is from wastes excreted by organisms, including livestock manure and human wastes, or from the degradation of particulate organic-N from plants and plant residues.

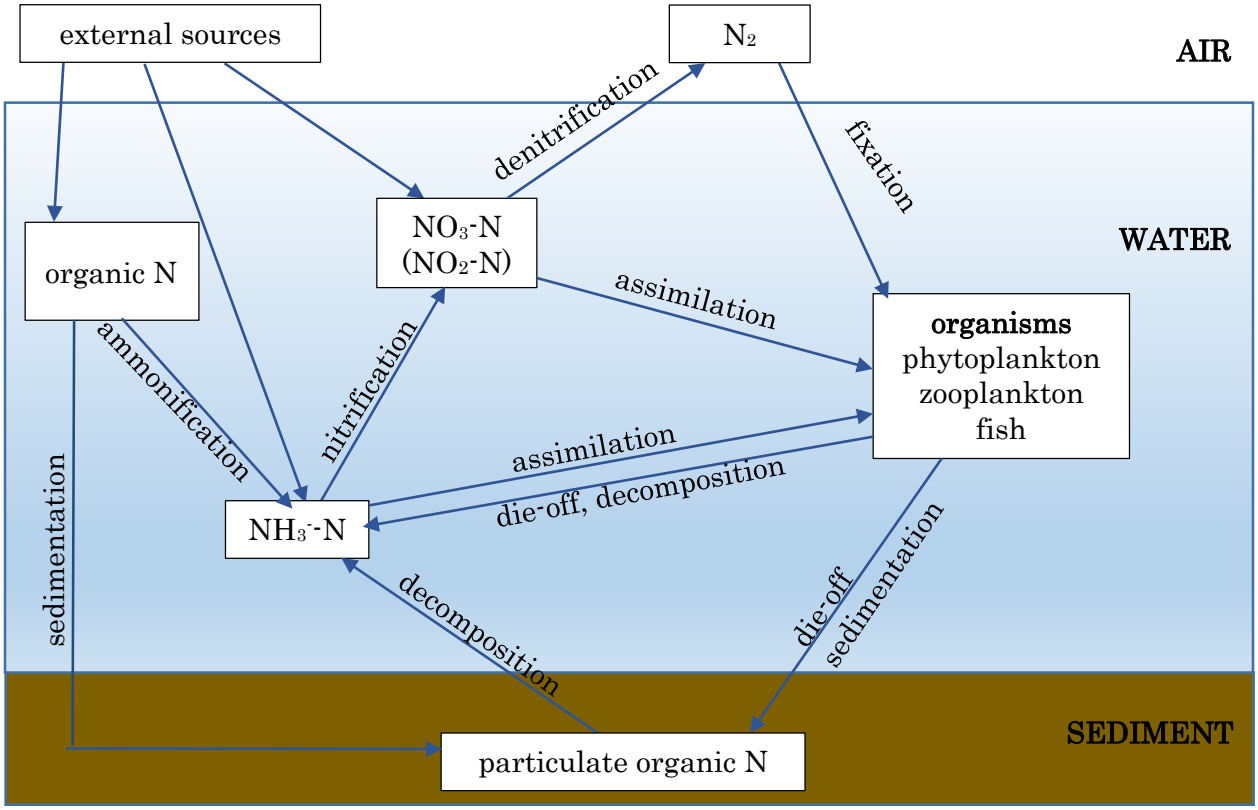

Figure 1. Schematic of N-cycle in freshwater. Major processes are sedimentation, decomposition, ammonification, assimilation, denitrification, and nitrogen fixation

Inorganic-N (NH_3-N, NO_3^--N, and NO_2^--N) are used by primary producer (phytoplankton) to build new cells. From there, nitrogen is further involved in food webs trough grazing by zooplankton. Zooplankton are then eaten by predators such as fish. Following their death, organisms settles and accumulates on lake bottoms as organic

matter. In the process of microbial decomposition, particulate organic matter is hydrolyzed into soluble components that are small enough to be taken up and metabolized by bacteria. Soluble organic N released from hydrolysis is then converted to ammonia via a process called ammonification. Ammonification is performed by a number of microorganisms under either aerobic or anaerobic conditions. Ammonia nitrogen can exist in two forms in natural waters: un-ionized ammonia (NH_3-N) and ammonium ions (NH_4^+-N). Balance between NH_3-N and NH_4^+-N depends on water pH. Un-ionized ammonia is toxic to fish and other aquatic life at a fairly low concentration. However, when water pH is below 9, the majority of ammonia exists as ammonium ions in water. In this dissertation of nutrient research, there is no need to differentiate ammonium ion from un-ionized ammonia. Therefore, ammonia nitrogen (NH_3-N) is used to represent the total of NH_3-N and NH_4^+-N.

Once released in water, NH_3-N can be used directly by microorganisms (phytoplankton and bacteria) as a nutrient for the growth. Under aerobic conditions, NH_3-N may also be oxidized to nitrate-nitrogen (NO_3^--N) via a process called nitrification. Nitrification is a two-step process mediated by specific autotrophic nitrifying bacteria in an aerobic environment (Gaudy & Gaudy, 1980). In the first step, ammonium is oxidized to nitrite-nitrogen (NO_2^--N) by bacterial species such as *Nitrosomonas* spp. The second step, oxidation of NO_2^--N to NO_3^--N, is mediated by species such as *Nitrobacter* spp. Both NO_2^--N and NO_3^--N also can be used as nutrients for biological growth.

When a water body becomes anoxic, NO_3^--N and NO_2^--N may be converted to nitrogen gas (N_2) via a multiple steps biological process called denitrification (Painter, 1970; Matsubara, 1970). In this process, NO_2^--N and NO_3^--N are utilized as electron acceptors by a group of facultative bacteria under anoxic conditions. NO_3^--N and NO_2^--N are reduced into nitrogen oxides (NO, NO_2), and then to nitrogen gas (N_2). Denitrification may results in a permanent N loss (a sink) from aquatic systems, which usually results in a nutrient

imbalance in lakes and reservoirs creating a nitrogen limiting condition (N-limiting) (Seitzinger, 1988; Nixon et al., 1996). Under nitrogen limiting conditions, certain organisms, such as certain Cyanobacteria species, can convert (fix) dissolved N_2 (N_2-fixation) into ammonia (Whitton et al., 2012) using an enzyme complex termed nitrogenase.

2.2.2. Phosphorus cycle

A phosphorus cycle is shown in Figure 2. Phosphorus enters water bodies through streams, runoff and nonpoint sources such as runoff from pasture and croplands. Other sources include urban runoff, non-agricultural rural runoff, and effluent from individual sewage treatment systems. Atmospheric deposition through aerosols, volcanic ash, and mineral dust is also important (Paytan & McLaughkin, 2007).

Phosphorus in aquatic systems occurs as organic or inorganic compounds in both soluble and insoluble forms. Inorganic dissolved forms include PO_4^{3-}, HPO_4^{2-} and $H_2PO_4^-$ that together are referred to as orthophosphate. Dissolved orthophosphates are commonly called soluble reactive phosphorus (SRP) because it is the form used by microorganisms in their simulation processes and may react with other dissolved substances. Orthophosphates can react with metal ions, such as iron, manganese, and calcium, forming insoluble precipitates. Orthophosphate can also be sorbed onto soil and other particles. When phosphorus is associated with metals or soil particles, it is called inorganic particulate phosphorus. Organic P can occur in a variety of compounds including phospholipids, nucleic acids, inositol phosphates, phosphoproteins, sugar phosphates and phosphoric acids (McKelvie, 2005). When P is associated with a carbon-based molecule (proteins, carbohydrates, and lipids) in plant or animal tissue, it is a part of particulate organic-P (Søndergaard, 2001).

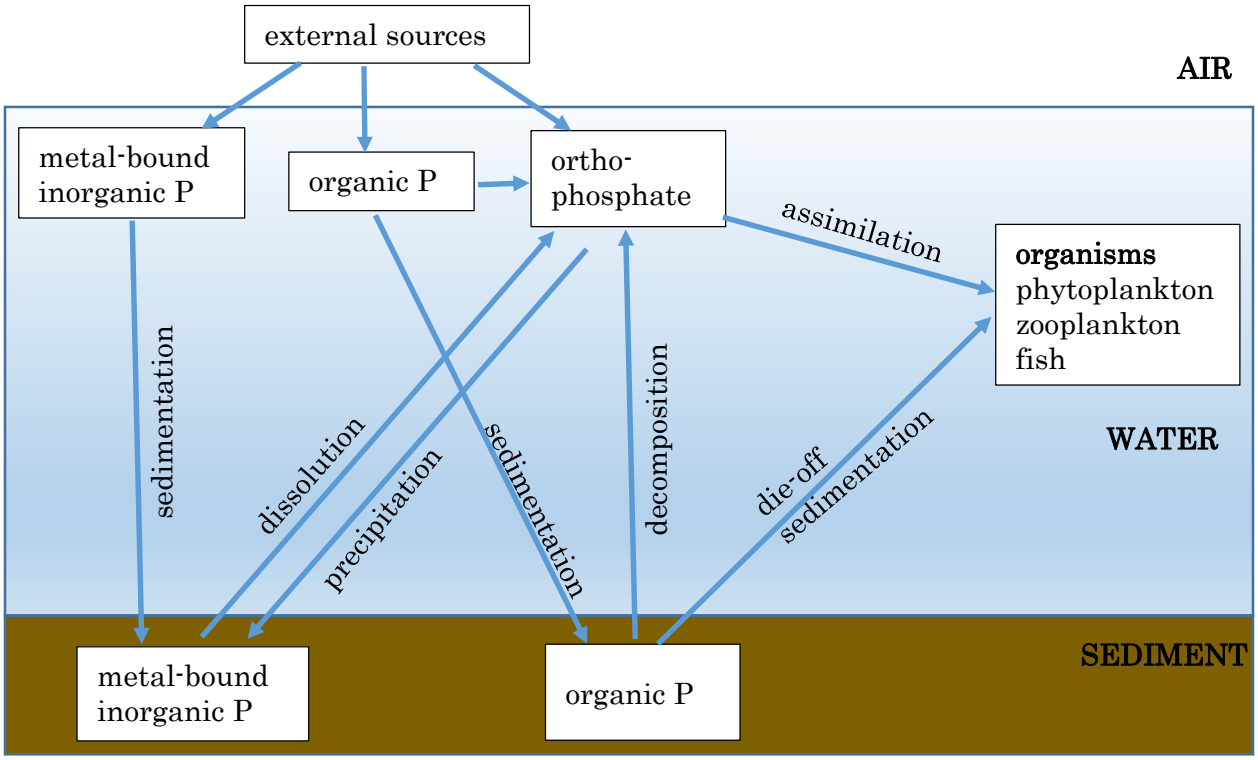

Figure 2. Schematic of Phosphorus cycle in water. Major processes are sedimentation, decomposition, precipitation, and assimilation

Phosphorus is introduced to water bodies as a mixture of organic and inorganic forms. The metal-bound P precipitates and organic-particulate P settle and accumulate in the lake sediments. Dissolved inorganic P (orthophosphate) can be used by phytoplankton and aquatic plants. P further flows through the main aquatic components in the food chains (phytoplankton-zooplankton-planktivorous fish-predatory fish). When organisms die off, they become organic matter. Organic matter is subsequently decomposed. In the process of decomposition, organic matter is hydrolyzed by microorganisms and organic P is converted to orthophosphate. Sediments may act as a source or as a sink of phosphorus (Böstrom et al., 1988). Orthophosphate may react with dissolved metals to form metal precipitates or be absorbed onto different particulate matter. Orthophosphate can also be adsorbed onto surfaces of Fe, Mn, and Al-(hydr)oxide, calcite, and clay particles (Søndergaard, 2001). Under aerobic condition, metal (Fe or Mn) bound phosphate precipitates are retained in the

sediments, and P is not available for the phytoplankton growth. However, P could be released back to the water column as result of chemical and biological processes. A well-known fact is that when the sediment-water interface in lakes become anaerobic, soluble P is released in the water column. Released P could be used again by phytoplankton and further involved in food webs. In contrast to N, P does not exist in a gaseous form and the cycle of P in water systems could be considered as a close cycle. (Detailed descriptions of P release mechanisms from sediments will be discussed in the following section).

2.3. Mechanisms of Sediment Nitrogen and Phosphorus Release

In eutrophic lakes, organic rich sediment is a huge reservoir for phosphorus, nitrogen and other nutrients for phytoplankton growth. Release of N and P from sediments depends on chemical and biogeochemical processes in sediments.

2.3.1. Mechanisms of sediment P release

Particulate P in sediments can be divided into two general categories: organic phosphorus and non-soluble orthophosphate. Organic phosphorus can be found in dead phytoplankton, remains of other plants, and refractory organics from decomposition. Inorganic orthophosphate may exist as metal phosphate precipitates (such as $AlPO_4$, $Ca_3(PO_4)_2$, $FePO_4$, and $Fe_3(PO_4)_2$) or be sorbed on to surfaces of metal-(hydr)oxide (such as FeOOH and $Al(OH)_3$), clay particles and organic matter. Therefore, both chemical and biological reactions in sediments play important roles in release of P from the sediment. Physical and chemical conditions such as temperature, pH, redox potential, sulfates, resuspension, and the presence of Ca, Mn, Fe, Al, and Mg in water have been found to affect P release (Kleeberg & Kozerski, 1997). These physical, chemical, and biological factors associated with P release from sediments are discussed further in the following paragraphs.

Chemical mechanism. The classic paradigm in limnology is that oxic conditions on the sediments-water interface regulates P release to the overlying water column. Einsele (1936) and Mortimer (1941) described P-sediment release as a process that depends on the binding potential of orthophosphate to metal precipitates, such as Fe and Mn precipitates, under varying redox conditions. Einsele (1936) showed that under oxidizing conditions P precipitated in the presence of insoluble ferric phosphate and iron-(hydr)oxydes(FeOOH) in the sediments, while in reduced condition, soluble P is released. Mortimer (1941, 1942) observed that phosphate (PO_4^{3-}) and Fe in bottom of Lake Esthwaite rose rapidly when hypolimnion become anoxic and both decreased when lake become aerobic during the fall turnover. Mortimer described that in the oxygenated sediment-water interface, Fe becomes oxidized and forms iron-(hydr)oxydes (FeOOH) that precipitates on the bottom of the lake. PO_4^{3-} is adsorbed by FeOOH forming FeOOH-PO_4 complexes. Under anoxic conditions, the reductive dissolution of the solid iron-(hydr)oxide results in a parallel dissolution of the previously adsorbed phosphate (Mortimer, 1941, 1942). In a more recent experimental study, release of SRP from anoxic sediments was found about 10 times faster than from the oxic-sediments (Newlin et al., 2005).

Phosphorus also can react with Al^{3+}, Ca^{2+}, Fe^{2+} or Fe^{3+} from precipitates, such as stregnite [$FePO_4 \cdot 2H_2O$], vivianite [$Fe_3(PO_4)_2 \cdot 8H_2O$], hydroxyapatite [$Ca_5(PO_4)_3(OH)$], monelite [$CaHPO_4$], variscite [$AlPO_4 \cdot 2H_2O$], reddingite ($Mn_3[PO_4]_2 \cdot 3H_2O$), and hureaulite ($Mn_5H_2[PO_4] \cdot 4H_2O$)(Böstrom, 1988; Søndergaard, 2001; Christophoridis & Fyiantos, 2006). Phosphorus, both inorganic and organic forms, can also be sorb to surfaces of Fe- and Al-(hydr)oxide, calcite, and clays (Søndergaard, 2001). Phosphorus adsorption to mineral surfaces happens by ion exchange (electrostatic attraction) or ligand exchange (hydroxyl substitution) with ligand exchange being more typical in sediments (Rhue & Harris, 1999). Sorption capacity and release from mineral surfaces is highly depend on the redox condition

(Van der Zee et al., 2003; Shenker et al., 2005; Druschel et al, 2006) and pH (Lijklema, 1976). Aluminum oxides are not easily reduced and may not result in a release of P under anoxic condition (Kopácek et al., 2000; Rydin et al., 2000). Anoxic conditions promote the reduction of insoluble FeOOH to soluble Fe^{2+} resulting in P release from the surfaces into the surrounding water (Einsele, 1936; Mortimer, 1941, 1942; Søndergaard, 2001; Hupfer & Lewandowski, 2008).

Under anoxic conditions, sulfur also plays an important role in the Fe-P relationship. Under lower redox potential, the reduction of both Fe and FeOOH, and SO_4^{2-} leads to formation of insoluble iron-sulfides (FeS_2, FeS) (Kleeberg & Schubert, 2000; Perkins &Underwood, 2001; Christophoridis & Fytianos, 2006). This could lead to Fe deficiency in the sediment-water interface consequently resulting in sediment-P release (Søndergaard et al., 1996; Hupfer & Lewandowski, 2008). On the other hand, dissolved sulfide consume oxygen on the sediment-water decreasing the thickness of the oxidized boundary layer. Thereby, interactions of the Fe, S, and P cycles may have important effects on orthophosphate availability.

Biological mechanism. As discussed in Section 2.2, microorganisms decompose organic matter that accumulates in eutrophic lakes. Decomposition of organic matter converts organic particulate P to dissolved P. Thus, decomposition of organic matter is an important and critical process in sediment-P release. Decomposition of organic matter happens under both anaerobic and aerobic conditions (Deinema et al., 1985; Wentzel et al., 1991). A number of studies revealed that aerobic decomposition of organic matter is faster than anaerobic decomposition. For example, Kristensen et al., (1995), who studied aerobic vs. anaerobic degradation of plant material in sediments, found that aerobic carbon mineralization was 10 times faster than the rate of anaerobic degradation. Results from a

study of Geurts et al. (2010) showed that removal of carbon from sediments, due to decomposition, was about two times faster under aerobic than under anaerobic degradation.

The rates of aerobic and anaerobic decomposition in sediments depends on the origin (sources), chemical composition, and age of the organic matter. The primary sources of organic matter in lake comprises of particulate detritus of phytoplankton and aquatic plants (autochthonous, internally produced), and organic matter carried by runoff and inflow into a lake (allochtonous). The microbial decomposition may run from hours to years depending on the chemical composition of the organic matter. A few studies pointed out that microorganism easily decompose the autochthonous (internally produced) organic matter (Kristensen & Holmer, 2001; Burdige, 2007). Dead phytoplankton cells can be easily decomposed and increases bacterial activity (Wilczek et al., 2005). Increase of trophic status of the lake usually results in an increase of bacterial activity (Chróst & Siuda, 2002). In a long-term laboratory experiment, Tessenow (1972) investigated the production of inorganic-P, Fe, and Si, by simulated sedimentation events of diatoms. Under both aerobic and anaerobic conditions, about 70% of P incorporated in diatom cells were released during the first a few weeks. Decaying biomass of Cyanobacterial blooms also may significantly accelerate sediment-P release. In their experiment, Chen et al., (2014) studied effect of settled dead Cyanobacterial biomass and seasonal temperature changes on phosphorus cycling in the sediments. Their study lake, Lake Taihu, is a eutrophic lake with frequent blooms of Cyanobacteria and P-release in summer months. The results show that phosphate concentrations increased from sediments where dry cyanobacterial material was added in comparison with sediments containing no cyanobacterial material. The results of these studies suggest that decomposition of organic matter, mainly dead phytoplankton cells in eutrophic lakes, would likely result in a substantially release of P and N from

sediments. Based on the discussion on the biological mechanism of P-sediment release, it could be pointed out decomposition of organic matter is an important source for P release.

2.3.2. Factors affecting sediment nutrient release

Factors, such as a pH, temperature, iron concentration, and resuspension important factors influencing P-sediment release (Søndergaard et al, 2003; Kleeberg & Kozerski, 1997).

pH. At higher pH, hydroxide OH-ions are likely to displace PO_4^- adsorbed to hydroxides (Lijklema, 1980). The released P will not re-adsorb until the pH has decreased (Boström et al. 1982). Laboratory experiments shows that at pH 10, P-sediment release rate was about two times higher than at pH 8 (Fisher & Wood, 2001). Similar results of higher P release with an increase of pH were reported by Seitzinger (1991), Wu et al. (2014) and Huang et al., (2005). Changes in the lake pH can result from photosynthetic activity in which plants and algae remove carbon dioxide (CO_2) from the water column, thereby raising the pH. Seitzinger (1991) indicated that during an algal bloom in the vertically well mixed Potomac River, pH was as high as 10.5 resulting in increased phosphorus release.

Temperature. Results from number of studies showed summer increases and winter decreases of P concentrations reveal that temperature is a factor affecting P release (Jensen & Andersen, 1992; Boers et al., 1998; Penn et al., 2000, Seling & Schlungbaum, 2003). The temperature effect on sediment-P release was explained by three facts: 1) temperature may increase phosphate solubility (Coffman & Kildsig, 1996; Wu et al., 2011), 2) higher temperature increases many biologically mediated processes (Jensen & Andersen, 1992; Gächter & Meyer, 1993; Liu et al., 2009; Wu et al., 2011), and, 3) a higher mineralization rate may result in a higher oxygen demand into the sediment surface. Therefore, higher temperatures that stimulate mineralization of organic matter in the sediment results in enhanced release of P (Boström et al., 1982; Gomez et al., 1998). Based on the observed

increase of P coupled with increase of temperature in summer months, some authors linked P release to temperature and biological activity (Jansen & Anderson, 1992; Boers et al., 1998; Søndergaard et al, 1999). Subsequently, less oxygen will penetrate into the sediments, thereby lowering the effect of oxygen on forming precipitates (Hupfer & Lewandowsky, 2008). As discussed earlier, iron-phosphate minerals are redox sensitive (Mortimer, 1941), and low redox potential can result in sediment-P release (Søndergaard, 2001).

Resuspension of sediments. Wind-induced resuspension of sediments results in higher concentrations of suspended material in the water column. Resuspended material leads to increasing contacts between sediment particles and water (Kristensen et al., 1992; Hamilton & Mitchell, 1997). Resuspension of sediments highly depends on water depth. Several studies found that the P-release varied depending on wind mixing and is actually quite common in shallow lakes (Jones & Welch, 1990; Søndergaard et al, 1992). However, intensity and periodicity of the wind mixing may vary causing only periodic release of P (Horppila & Nurminen, 2001; Einarsson et al., 2004).

Fe:P ratio: Since P has a higher affinity to iron precipitates, iron availability in the sediments is another important factor for the sediment's ability to bind P. The Fe:P ratio corresponds to the amount of available Fe mineral to which P can sorb. As long as there are free, binding sites of Fe in oxidized sediment, P retention rates will be positive. In a study of 15 lakes Jensen et al. (1992) found that under oxic condition sediment-P release was slower when Fe:P ratio was above 15:1 (by weight). The authors believed that keeping Fe:P ratio above 15:1 prevented P release from sediments by keeping the surface sediment oxidized (Jensen et al., 1992). Another study suggested that the ratio should be 10:1 (Caraco et al., 1993). Different thresholds of proposed Fe:P ratios implies that the use of a ratio is not a reliable estimate of capacity of iron to bind phosphorus.

2.3.3. Mechanism of sediment nitrogen release

Converting organic nitrogen in cell materials to ammonia (NH_3-N) is ammonification (also known as mineralization). The rate of ammonification usually increases with the temperature. In general, the rate of ammonification doubles with an increase of temperature of 10ºC in the temperature range 15-40ºC (Kadlec & Reddy, 2001). Ammonification can occur under aerobic and anaerobic conditions. Anaerobic ammonification proceeds at slower rate than in an aerobic environment (Reddy et al., 1984).

Kinetic studies of sediment nutrient release found that under aerobic conditions specific ammonia-release rate coefficients ranged from 0.05-0.2/d, while the anaerobic ammonia release rate was 0.007/d (Hamilton & Schadow, 1997; Robson & Hamiltion, 2004; Özkundakci et al., 2010). Based on these findings, the ammonia release rate from sediments under aerobic condition is several times faster than the rate under anaerobic condition. Results from field studies also show that sediment nitrogen release under aerated conditions was 363 mg/m^2/d, while when sediment was maintained the anoxic nitrogen release rate was less than 100 mg/m^2/d in the same lake (Özkundakci et al. 2010). In addition, temperature affects the rate of biological reactions. Hence, relatively higher temperatures in summer lead to an increase in decomposition rate of organic matter, and consequently to an increase of nutrients released from sediments. Similarly, nitrification rate increases gradually from <10°C to 30°C (Thamdrup & Fleischer, 1998).

2.4. Seasonal Vertical Distribution of Nutrients in Temperate Lakes and Reservoirs

In temperate lakes, there are clear seasonal changes in mixing conditions that affects nutrient distribution in deep lakes. In early spring as the ice cover melts, the surface water warms up. As surface water, temperature reaches 4˚C, when water reaches its highest density. Heavier surface water sinks and causes vertical mixing of the water

column. This is called spring "turnover". This mixing allows diffusion of oxygen deeper in the water column and causes nearly even distribution of nutrients throughout the water column (Wetzel, 2001; Lampert, 2007).

In late spring and early summer, the sun heats the water and the temperature on the surface layer of the water body increases. As the season proceed toward summer, surface water continue to warm, the surface water becomes lighter and floats over the cold water forming a warmer surface layer called epilimnion and the colder deep layer called hypolimnion. Between the epilimnion and the hypolimnion layers is a relative thin layer, 1 to 2 meters in depth, with rapid temperature change. This layer is called metalimnion or thermocline (Birge, 1897). This condition is commonly referred to as a thermal stratification or stagnation. The thickness of the epilimnion dependent on the lake surface area, solar radiation, air temperature, and lateral circulation and movement of the surface water. Water in the epilimnion is well mixed mainly due to wind effect (Chapman, 1996). Most phytoplankton growth is in this layer due to higher light availability. In the epilimnion DO concentrations remain high because photosynthesis and absorption of oxygen from the atmosphere. The metalimnion acts as a barrier to mixing of water layers. Reduced mixing of lake water reduces transfer of DO from the epilimnion to the hypolimnion. The hypolimnion remains cut off from all sources of oxygen. In addition to reduced mixing, decomposition of organic matter may result in further DO depletion in the hypolimnion. Therefore, the hypolimnion often becomes anoxic. As has been already discussed in Section 2.3.1., anoxia promotes P-sediment release (Mortimer, 1941, 1942; Boström, et al., 1982). Release of N and P from sediments is referred to as internal loading. In stratified lakes, nutrients released from sediments accumulates in the hypolimnion.

In the fall temperatures decrease and water in epilimnion cools down. Surface water becomes dense and sinks. The lake “turns over” (fall turn over) and becomes completely

mixed again. Mixing eliminates differences in temperature and water densities. Under uniform water density, wind easily mixes the water increasing circulation of water masses. Increased circulation of water allows diffusion of oxygen from the surface layers (Wetzel, 2001, Kalff, 2002; Lampert, 2007). In a mixed, non-stratified water column, water above the sediment is normally well oxidized and the redox potential is sufficient enough to maintain iron in an oxidized form thereby keeping P trapped in sediments (Mortimer, 1941, 1942; Boström, et al., 1982; Penn et al., 2000).

In the winter, if ice forms, the ice blocks the light and prevents reaeration from the atmosphere. The decomposition of organic matter continue to consume oxygen on the bottom of the lake and may result in DO depletion. The DO depletion may result in a winter fish kill. The released nutrients can accumulates on the bottom, due to reduced mixing. These nutrients are brought back to the surface during the spring turnover causing a rapid phytoplankton growth (Ji, 2007).

2.5. Nutrient Requirements for Phytoplankton Growth

Various inorganic nutrients are required as building block for life in aquatic systems. Certain elements for cell development and growth are required in large quantities and hence are called macronutrients. Most important macronutrients for phytoplankton growth are carbon, oxygen, nitrogen, phosphorus, and silicon (Horne & Goldman, 1994; Reynolds, 2006). Among these macronutrients, the most important macronutrients are carbon (C), nitrogen (N) and phosphorus (P) in study phytoplankton growth.

Redfield (1958) studied the proportion of N, P, and C in phytoplankton and seawaters. Based on statistical analysis of a large set of water and phytoplankton samples, Redfield found that the ratios of C:N:P were close to 105:15:1 and remained the same in sea water from coastal to open ocean regions. The ratio and atomic ratio of C:N:P in marine organic matter (dead and living phytoplankton) was close to 106:16:1 and was remarkably

constant. This congruence in ratios between biota and the surrounding aquatic environment lead Redfield to suggest that the C:N:P ratio indicated a balanced flow in and out from the biota and that the biota is the main factor in quantifying the biochemical cycles in water (Redfield, 1958). Although phytoplankton vary greatly from species to species, chemical composition, and photosynthesis/respiration process of phytoplankton cells remain relatively constant and was idealized as follows (Stumm & Morgan, 1981):

$$106CO_2 + 16NH_4^+ + HPO_4^{2-} + 8H_2O \leftrightarrow \{C_{106}H_{263}O_{110}N_{16}P\} + 107O_2 + 14H^+$$

protoplasm

Based on the stoichiometric relationship in the above reaction, the N to P ratio of 16:1 for phytoplankton growth is required. When this ratio is converted to a mass unit (mg or g), then the N to P ratio is 7.2:1. The ratio 7.2:1 has been widely accepted as an optimal ratio for phytoplankton growth, and deviation from this ratio indicates that either N or P will be the limiting factor for the growth. The ratio below 7.2:1 indicates nitrogen limitation, while ratio above 7.2:1 indicates that P is the limiting factor for the growth. This ratio, often referred as the "Redfield ratio" has been used as a benchmark and enables scientists to study the biochemical cycles and determine which nutrient might be limiting for the phytoplankton growth.

2.5.1. Impact of nitrogen to phosphorus ratio on phytoplankton growth

As discussed earlier, N and P usually are the limiting macronutrients that control phytoplankton growth in lakes and reservoirs. A stoichiometric N:P ratio of 7.2:1 by weight is widely used to determine the nutrient balance and the limiting nutrient in a lake. Based on this stoichiometric relationship, the amount of phytoplankton that may grow is controlled by the least available nutrient, N or P. For many years, reducing the nitrogen load has been the common practice for controlling algal growth (Schindler et al., 2008, Schindler et al., 2012). However, this approach was proven ineffective and may have

resulted in more growth of Cyanobacteria. A long-term study on Lake 227 in the Experimental Lake Area, Canada showed that reducing N-inputs without P reduction favored growth of nitrogen-fixing Cyanobacteria (Schindler et al., 2008). Nitrogen fixation was sufficient enough to allow biomass to continue to produce in proportion to the amount of P and the lake remained highly eutrophic (Schindler et al., 2008). In addition to the N_2-fixing capability of some Cyanobacteria species, Cyanobacteria are generally better N-competitors, but poorer P-competitors as compared to other phytoplankton groups (Smith, 1983). Based on the analyses of nutrient and phytoplankton data from 17 temperate lakes worldwide, Smith (1983) found a tendency for Cyanobacteria blooms to occur when the TN:TP ratio was below 29:1 by weight, but for Cyanobacteria to be rare when the ratio was above 29:1. Smith (1983) pointed out that although N:P ratio alone might not be sufficient to explain dominance or absence of Cyanobacteria, maintaining an epilimnetic TN:TP ratio greater than 29:1 may be used as a management strategy for controlling Cyanobacteria blooms. Later, Smith and his coworkers (Smith et al., 1995) reported that a TN:TP ratio of 22:1 provides a boundary for the growth of nitrogen fixing Cyanobacteria.

The application of the N:P ratio to determine the tendency of Cyanobacteria blooms and for lake management has received significant attention as well as debate from researchers. Havens et al. (2003) found that use of N:P ratio alone was not able to explain dominance of non-nitrogen fixing Cyanobacteria in an eutrophic lake. High turbidity was the explanation for the reason of a bloom of non-nitrogen fixing taxa of Cyanobacteria. Based on statistical analyses of observations from 99 lakes around the world, Downing et al. (2001) concluded that Cyanobacteria blooms are more strongly correlated to variation in TP, TN, Chl-*a*, or total phytoplankton biomass than N:P ratio. The authors pointed out that correlation between Cyanobacteria population and TP could be the most useful for predicting Cyanobacteria blooms, and suggested that alternative explanations for

Cyanobacteria dominance, such as turbidity, CO_2 depletion, and buoyancy regulation, should be studied.

To test the hypothesis that the N:P ratio influences phytoplankton species composition, and especially that Cyanobacteria are favored by a low N:P ratio, Levine and Schindler (1999) conducted mesocosm experiments in the Experimental Lakes Area (ELA), Ontario. Although Cyanobacteria blooms were observed in some of the treatments, the authors concluded that results of this study did not support the hypothesis and suggested that rising pH and plunging CO_2 concentration played a role in the rise to dominance of cyanobacteria and chlorophytes.

Based on the discussion above, different thresholds of the N:P ratio (Smith, 1983; Smith et al., 1995; Havens et al., 2003) implies that using the TN:TP ratio to predict Cyanobacterial blooms is not a reliable method in lake management practices. The ratio itself might not be enough to explain the variations in phytoplankton growth and composition. Phytoplankton growth rate and potential dominance of certain species depend on concentrations of N and P. Different phytoplankton species differ in their kinetics on nutrient uptake, assimilation, and storage capacities. Moreover, competition for limiting nutrients was a key factor in the determination of phytoplankton community composition (Tilman et al., 1982; Sommer, 1989). In natural aquatic systems, many different species have different growth characteristics that allow them to live in the same ecosystem competitively. Tilman's resource competition theory states that under nutrient limitation in equilibrium conditions, those species, which have either the lowest requirement for the limited resource or the highest ability to utilize it, will succeed in competition (Tilman et al, 1982). Thereafter, growth rate of phytoplankton is directly related to nutrient concentrations and growth rates vary among phytoplankton species in responses to

different nutrient concentrations (Tilman et al., 1982). The impact of N and P concentrations on phytoplankton growth rates is discussed in the following section.

2.5.2. Impact of nitrogen and phosphorus concentrations on phytoplankton growth rates

The relationship between limiting nutrients and phytoplankton growth rate is species specific (Tilman et al., 1982; Helterman & Toetz, 1984; Sommer, 1986). Different kinetic models have been used to study biodegradation processes. The most commonly used relationship between reproduction rate of organism (phytoplankton biomass) and concentration of the limiting nutrient is the Monod model (Monod, 1942):

$$\mu = \frac{\mu_{max} S}{(K_s + S)} \qquad \text{(Equation 2.1)}$$

where: μ= specific growth rate (T^{-1})
μ_{max}= maximum growth rate coefficient (T^{-1})
S = concentration of limiting nutrient (ML^{-3})
K_s = half-saturation constant for the growth (ML^{-3}).

In Monod model, the growth rate is related to the concentration of a single growth-limiting substrate through the parameters μ_{max} and K_s. For very high values of S the Monod kinetics become a zero order in S (Mata-Alvarez, 2003), then

$$\mu = \mu_{max} \qquad \text{(Equation 2.2)}$$

For values of S much smaller than K_s, the Monod equation gives a first order kinetics in S (Mata-Alvarez, 2003):

$$\mu = \frac{\mu_{max}\ S}{K_s} \qquad \text{(Equation 2.3)}$$

The Monod equation also can be presented as nutrient uptake rate (Droop, 1973):

$$v = \frac{V_{max}\ S}{(K_s + S)} \qquad \text{(Equation 2.4)}$$

where: v= nutrient uptake rate ($ML^{-3}T^{-1}$)
V_{max}= maximum uptake rate coefficient ($ML^{-3}T^{-1}$)
S = concentration of limiting nutrient (ML^{-3})
K_s= half-saturation constant for nutrient uptake (ML^{-1})

Both N and P are required for the synthesis of a new biomass. As nutrient availability changes, in terms of N or P concentration, the nutrient condition may favor the growth of certain species and result in more growth and dominance of those species. Organisms with higher values of μ_{max} would grow faster than the organisms with a lower value of μ_{max} and therefore organisms with higher values of μ_{max} may become dominant when the nutrient concentration is high. However, the half-saturation constant (K_s) is an important characteristic of phytoplankton growing in nutrient limiting environments (Eppley et al., 1969). The phytoplankton species with low half-saturation constant values have a greater ability to take up nutrients at low concentrations. Lower half-saturation constants make certain species better competitors for N or P when they are available at low concentrations (Mulder & Hendriks, 2013). Values of μ_{max}, V_{max} and corresponding K_s found in different studies for phytoplankton species are presented in Table 1.

Table 1. Phytoplankton specific maximum growth rates and half saturation constants for nitrogen and phosphorus

Phytoplankton class/ phytoplankton genera	Nitrogen		Phosphorus		Reference
	μ_{max} (T^{-1}) V_{max} ($ML^{-3}T^{-1}$)	K_s (ML^{-3})	μ_{max} (T^{-1}) V_{max} (ML^{-3})	K_s (ML^{-3})	
Cyanophyceae (Cyanobacteria)					
Gloeocapsa alpicola	0.0182 mg/L.h^{-1}	0.0798* mg/L*			Helterman & Toetz, 1984
Microcystis aeruginosa	0.0174 mg/L.h^{-1}	0.0228* mg/L*			Helterman & Toetz, 1984
			0.010 h^{-1}	0.002 mg/L	Amano et al., 2010
Microcystis wesenbergii			0.01 day^{-1}	0.0005 mg/L	Ahlgren, 1985
Microcystis novacekii	0.021 h^{-1}	0.0098** mg/L			Watanabe & Miyazaki, 1996
Anabaena sp.	0.007 mg/L.h^{-1}	~0*			Helterman & Toetz, 1984
			0.033 h^{-1}	0.0110 mg/L	De Nobel et al, 1997
Aphanisomenon sp.				0.0490 mg/L	Degerholm et al., 2006
			0.025 h^{-1}	0.0210 mg/L	De Nobel et al, 1997
				0.0074 mg/L	Kromkamp, 1989
Anabaena flos aque	0.51 h^{-1}	0.0311 mg/L**			Gu & Aleksander, 1893
	0.01 h^{-1}	0.0011 mg/L*			Gu & Aleksander, 1893
	0.14 h^{-1}	0.0609 mg/L***			Gu & Aleksander, 1893
	0.0360 h^{-1}	0.0011 mg/L	0.028 h^{-1}	0.0129 mg/L	Hu, 1993
				0.0493 mg/L	Kromkamp, 1989
Planktotrix agardhii			0.017 h^{-1}	0.0280 mg/L	Ahlgren, 1985
Cylindrospermopsis raciborskii			0.067 h^{-1}	0.0025 mg/L	Isvánovics et al, 2000
Nodularia sp.				0.1078 mg/L	Degerholm et al., 2006
Chlorophyceae					
Actinastrum	0.0526 mg/L.h^{-1}	0.1497* mg/L*			Helterman & Toetz, 1984
Chlamidomonas reinhardii	0.0256 mg/L.h^{-1}	~0* mg/L*			Helterman & Toetz, 1984
Monoraphydium sp.	0.0158 mg/L h^{-1}	0.0218* mg/L*			Helterman & Toetz, 1984
Chlorella vulgaris	0.0195 mg/L h^{-1}	0.0125* mg/L*			Helterman & Toetz, 1984
Chlorella pyrenoidosa	0.0175 mg/L. h^{-1}	0.0035* mg/L*			Helterman & Toetz, 1984
Selenastrum capricornutum	0.0249 mg/L. h^{-1}	0.0221* mg/L*			Helterman & Toetz, 1984
Scenedesmus spinosus			0.1160 h^{-1}	0.0072 mg/L	Shafik, 1991
Scenedesmus obliquuis	0.021 mg/L h^{-1}	0.0154* mg/L*			Helterman & Toetz, 1984
Scenedesmus quadricauda	0.058 h^{-1}	0.0700**mg/L			Watanabe & Miyazaki (1996)
Cosmarium abbreviatum			0.0210 h^{-1}	0.00035 mg/L	Spijkerman & Coesel (1996)
Cosmarium pinque			0.0430 h^{-1}	0.0012 mg/L	Spijkerman & Coesel (1996)

Table 1. Phytoplankton specific maximum growth rates and half saturation constants for nitrogen and phosphorus (continued)

Phytoplankton class/ phytoplankton genera	Nitrogen		Phosphorus		Reference
	μ_{max} (T^{-1}) V_{max} (ML^{-3})	K_S (ML^{-3})	μ_{max} (T^{-1}) V_{max} (ML^{-3})	K_S (ML^{-3})	
Bacillariaophyceae (diatoms)					
Cyclotella sp.	0.00171 h^{-1}	0.0129 mg/L	0.029 h^{-1}	0.0073 mg/L	Hu, 1993
			0.0120 h^{-1}	0.014 mg/L	Amano et al., 2010
Naviculla pelliculosa	0.0368 mg/L.h^{-1}	0.0972* mg/L			Helterman & Toetz, 1984
Hanzchia amphioxys	0.0119 mg/L.h^{-1}	0.0578* mg/L			Helterman & Toetz, 1984
Nitzchia W-31 O'Kelly	0.0465 mg/L.h^{-1}	0.0361* mg/L			Helterman & Toetz, 1984
Nitzchia W-32 O'Kelly	0.0710 mg/L.h^{-1}	0.0370* mg/L			Helterman & Toetz, 1984
Synedra fifliformis			0.027 h^{-1}	0.0001 mg/L	Tilman et al, 1982
Stephanodiscus handshii			0.042 h^{-1}	0.0045 mg/L	Donk & Kilham, 1990
Stephanodiscus yellowstonensis	0.011 h^{-1}	0.0010 mg/L			Roh, 2000
Asterionella formosa			0.027 h^{-1}	0.0008 mg/L	Donk & Kilham, 1990
	0.016 h^{-1}	0.0007 mg/L			Roh, 2000
Fragillaria crotonensis			0.03 day^{-1}	0.0013 mg/L	Donk & Kilham, 1990
	0.02 h^{-1}	0.0007 mg/L			Roh, 2000***
Dinoflagellatae					
Peridinium cinktum		0.378** mg/L			Berman & Dubisky, 1985
Peridinium quatunense				0.1568 mg/L	Berman & Dumbinsky, 1985

Note: * μ_{max} and K_s are calculated for nitrate, ** μ_{max} and K_s are calculated for ammonium, ***μ_{max} and K_s are calculated for urea, *** nitrogen source is not specified

Analyses of nutrient kinetic parameters, shown in Table 1, provide some general understanding of impact of nutrient concentrations on phytoplankton growth. Green algae and diatoms have relatively higher μ_{max} and V_{max} values for both N and P compared to Cyanobacteria. When nutrients are plentiful, green algae and diatoms will grow faster than Cyanobacteria under normal environmental conditions. In contrast, Cyanobacteria have relatively lower μ_m and V_m values, which indicate slower growth as compared to green algae and diatoms at high concentrations of N and P.

On the other hand, in terms of K_s, from the data provided in Table 1, several diatoms have K_s for nitrate of 0.035 to 0.098 mg/L, which were higher than other phytoplankton species studied. The higher half saturation constants would make diatoms relatively less successful in N-limited conditions. The average K_s of 0.027 mg/L for green algae were close to the average K_s for Cyanobacteria genera. Similar half saturation constants of both classes gave them equal opportunity to grow at lower N concentrations. However, the K_s for N_2-fixing Cyanobacteria was close to zero and lowest compared to green algae, diatoms, and non-nitrogen fixing Cyanobacteria. Therefore, under low N concentration conditions, lower than K_s, N_2-fixing Cyanobacteria may outgrow the other phytoplankton species. In contrast, for P uptake, the K_s value for Cyanobacteria is typically higher, which means that their growth rate would be significantly lower when P is less available. In addition to the nutrient balance and concentrations, other factors, such as temperature and phytoplankton density, also need to be considered in analysis of algal growth. More about nutrient requirements and its impact on Cyanobacteria growth will be discussed in Section 2.9.

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2.6. Phytoplankton Seasonal Succession

Plankton ecologists have been observing and studying seasonal variation of phytoplankton for many years (Pearsall, 1930, 1932; Hutchinson, 1967; Sommer et al., 1986; Interlandi et al, 1999; Huszar et al., 2003; Dupuis & Hann, 2009). Phytoplankton populations in lakes and reservoirs are composed of different species. Variation in phytoplankton species composition in a lake follows a similar seasonal pattern from year to year and among lakes of similar trophic status (Tilman et al., 1982). This seasonal periodicity of regular substitution (replacement, sequence) of species is called seasonal phytoplankton succession (Wetzel, 2001; Reynolds, 2006; Mitsch & Gosselink, 2007). Such successional patterns in phytoplankton composition could be expressed as seasonal changes in total biomass, species richness, and diversity.

Factors that influence phytoplankton succession can be allogenic or autogenic. Succession caused by the organisms themselves is called autogenic (life cycle, competition, predation, parasitism, allelopathy, and other factors under biological control), when distribution of species is governed by its response to the environment (temperature, light, turbulence, water chemistry, and other external factors) it is called allogenic succession (Smayda, 1980; Tilman et al., 1982; Sommer, 1987; Lampert, 2007). Allogenic and autogenic, however, are not mutually exclusive between each other. For example, annually temperature changes, stratification, and water movement are among the important allogenic factors influencing development of the phytoplankton community, whereas light could have both autogenic (light attenuation by phytoplankton and detritus) and allogenic (daylight, mixing depth) influences. Higher the phytoplankton density results in steeper the light gradient. This will affect not only the distribution of phytoplankton through the water column, but also will increase the selective advantage for motile phytoplankton (Lampert,

2007). Since phytoplankton succession depends on environmental factors, generalization for different lakes is difficult to make. The phytoplankton succession varies regionally and may vary from year to year and from lake to lake in response to change to local conditions.

One attempt to explain seasonal succession of phytoplankton in correlation with physical and biological factors is the Plankton Ecology Group (PEG) model. The PEGroup, which consists of 30 plankton ecologists, developed a conceptual model based on a comparative study of phytoplankton and zooplankton succession in 24 temperate lakes (Sommer et al., 1986). The model correlates seasonal changes in phytoplankton biomass and species variation to changes in environmental factors including light, temperature, nutrient availability, and mixing of the water column. The model summarizes the seasonal variations in phytoplankton and zooplankton in 24 sequential events (patterns) (Sommer et al., 1986).

General trends in phytoplankton and zooplankton variations are shown in Figure 3, where intensity of controlling environmental factors are indicated by the thickness of the black horizontal bars beneath the biomass graph. Phytoplankton succession in eutrophic lakes typically has a spring peak (spring maximum), which happens after the spring turnover. In this period, temperatures and daylight period are increasing, and nutrients become more abundant due to mixing. The rapidly increased phytoplankton population consists of fast growing species. Growing zooplankton are then grazing on phytoplankton. Because of grazing phytoplankton population decreases, which leads to food limitation for zooplankton. Decreasing of both phytoplankton and zooplankton results in a period called 'clear-water' phase. In this phase, nutrients may accumulate. The lack of grazing pressure and increased nutrient concentrations in early summer gives an opportunity to phytoplankton to grow and to reach the second peak (summer peak). During that period,

species richness is high, consisting of small sized species, which are susceptible to grazing, and slow growing larger sized colonies, which is resistant to zooplankton pressure. As phytoplankton grow, the nutrients are consumed and become a limiting factor for growth, causing a rapid reduction in biomass. Upon fall as temperatures and day-length decrease, phytoplankton population also decreases. However, during fall turnover nutrient concentrations may increase due to mixing which in turn may result in a slight increase of phytoplankton. After the fall, peak phytoplankton continues to decrease in general trend (Sommer, 1986).

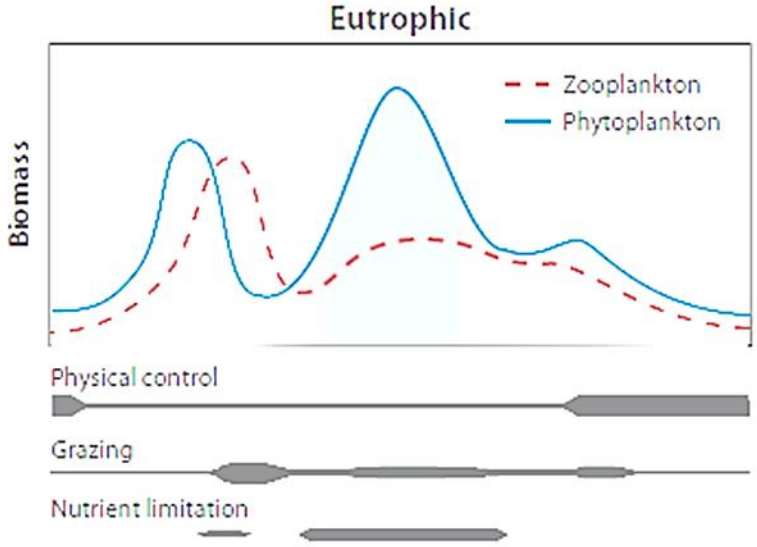

Figure 3. The original PEG model.
Seasonal (winter through autumn) biomass patterns in eutrophic water bodies. Focus on phytoplankton (blue solid line) (dark shading, inedible for zooplankton; light shading, edible for zooplankton). The thickness of the horizontal bars indicates the seasonal change in relative importance of physical factors, grazing, nutrient limitation, fish predation, and food limitation (adopted from Sommer et al., 2012)

The PEG model (Sommer et al., 2012) is a good starting point to illustrate the seasonal variation in the main growth factors for phytoplankton. In the PEG model the seasonal patterns of major phytoplankton species are described based on the observed succession of phytoplankton in Lake Constance (an N-limited lake) and was compared with 23 other lakes (Sommer et al., 1986). Briefly, in spring phytoplankton population consists of

fast growing species such as small diatoms and in some lakes large diatoms, Cryptophyceae, and small green algae (Sommer et al., 1986). According to nutrient kinetic parameters included in Table 1, diatoms have relatively higher maximum growth rates (μ_m) and higher specific nutrient uptake rates (V_m) for N and P than the rest of the phytoplankton groups. Their higher growth rates make diatoms good nutrient competitors and grow fast when nutrients concentrations are higher. Mixing of the water column is beneficial to keep diatoms suspended (Reynolds, 2006). In addition to N and P, diatoms require dissolved silica (Si) to build their cells. After "clear water", Cryptophyceae, and inedible green algae become dominant and deplete P concentrations. In addition, most of the large colonies of green algae, similar to diatoms, require mixing to retain suspension in the water column. Green algae usually have higher requirements for P (Tilman & Kielsing, 1984) and decrease rapidly under a P-limited condition (Sommer et al., 1986). That condition gives opportunity for growth of large diatoms such as *Asterionella* and *Fragilaria*. *Asterionella* and *Fragilaria* may grow well at low P and high Si concentrations. However, Si usually becomes exhausted after a higher spring development of diatoms (Sommer, 1991). In addition, these algae can use their advantages only if kept in suspension due to turbulence. A summer phytoplankton population consists of large dinoflagellates (*Ceratium*), which could co-dominate with Cyanobacteria. Both dinoflagellates and Cyanobacteria have relatively lower μ_m and V_m values for both N and P, which implies slower growth rates compared to other phytoplankton groups. Dinoflagellates and Cyanobacteria also have a high resistance to grazing due to the bigger sized cells. In addition, dinoflagellates are able to migrate vertically, while Cyanobacteria can regulate buoyancy. Vertical migrations make them able to adjust their position in the water column and to exploit vertical gradients of light and nutrient sources in stratified lakes.

Nitrogen depletion, found in one of 24 lakes during a stratified period, favors a shift to nitrogen-fixing species of filamentous blue-green algae (*Anabaena, Aphanizomenon*). These Cyanobacteria have the ability to fix N_2 from the atmosphere, which makes them well adapted to a nitrogen-limited condition. However, Cyanobacteria are also "poor competitors" for P (Fogg et al., 1973, Smith, 1983), which makes them less competitive in P-limited condition. Towards fall, increased mixing and nutrient concentrations may result in growth of filamentous and large algae (diatoms, *Ceratium*, green algae). However, a decrease of underwater light and temperatures results in a general reduction of phytoplankton population (Sommer et al., 1986).

Although the PEG model might not fit to all phytoplankton community changes, the model provides a conceptual framework for interpretation of phytoplankton succession regarding factors such as temperature, light, mixing, nutrient availability, competition, and loss processes. Phytoplankton are very sensitive to the changes in factors such as temperature and nutrients, and any changes in these factors usually results in deviation from typical phytoplankton succession. Therefore, changes in natural phytoplankton succession and community structure are an essential feature in lakes and reservoirs trophic status assessment.

A long-term study on Lake 227 in the Experimental Lake Area, Canada showed that manipulation in nutrient status resulted in change phytoplankton community (Schindler et al, 2008). The phytoplankton population shifted from green algae and non-fixing Cyanobacteria species to N_2-fixing Cyanobacteria species. In recent decades, eutrophication of the water bodies have resulted in increased phytoplankton growth, decreased phytoplankton diversity and shifts in typical phytoplankton population structure (Schindler, 2008). Eutrophic lakes have been more often associated with an increase of

intensity and frequent blooms of Cyanobacteria (Oliver & Ganf, 2000; Paerl & Huisman, 2008; Schindler et al, 2008; Smith & Schindler, 2009).

2.7. Cyanobacterial Growth

Cyanobacteria are ancient photoautotrophic prokaryotes that appear in the fossil records 2-3 billion years ago (Castenholz, 1992). Cyanobacteria are comprised of unicellular to multicellular prokaryotes that possess Chlorophyll-*a* and perform oxygenic photosynthesis (Castenholz & Waterbury, 1989). Excessive growth and blooms of Cyanobacteria are the most visible symptoms of accelerated eutrophication of freshwater ecosystems (Schindler et al., 2008; O'neil, et al., 2012; Paerl et al., 2014). Major problems and concerns associated with phytoplankton and Cyanobacteria blooms include reduced water clarity, offensive odor and taste from live and dead phytoplankton biomass, and low and even complete consumption of DO near the bottom of water bodies, which subsequently may result in stresses on or even fish kills (Schindler, 2012; Smith et al, 1999). In addition, toxins released by some Cyanobacteria species are harmful for human and aquatic biota (Downing et al., 2001; Scheffer, 2004; Codd et al., 2005). Formation of surface mats of Cyanobacteria also contribute to aesthetic problems and impair recreational uses.

Frequent and prolonged Cyanobacteria blooms become a threat to water quality leading to reduction of designated uses, such as drinking water supply, recreation, irrigation, fishing, and swimming in lakes and reservoirs. In 2007, a cyanobacteria bloom in Lake Taihu, one of the largest freshwater lakes in China, caused the City of Wuxi to shut down its water supply system resulting in more than 2 million people staying without water supply for several weeks (Paerl et al., 2011). In August of 2014, algal bloom occurred in Lake Erie and at the same time, cyanotoxins were detected in treated water of City of Toledo, Ohio. This event forced the city to issue a "Do Not Drink" water order that affected

nearly half million people (EPA 2015). In North Dakota, eutrophication has caused water quality concerns in many lakes and reservoirs. Therefore, the algal blooms due to aeration are a threat to drinking the water industry (EPA, 2009). Reducing Cyanobacterial growth and frequent blooms become a challenge worldwide.

Cyanobacteria have ecological and physiological features giving them the capability to overgrow other algae (Oliver & Ganf, 2000; Paerl & Huisman, 2008; Schindler et al, 2008; Smith & Schindler, 2009).

2.7.1. Cyanobacteria nutrient requirements

It has been already discussed in Section 2.5.1.that Cyanobacteria can grow well in N-limited conditions. Cyanobacteria similarly to other phytoplankton species utilize different sources of N including ammonium, nitrate, nitrite, urea, arginine, and glutamine, however some Cyanobacteria species have an unique ability to utilize N_2 from the atmosphere (Flores & Herrero, 2005). Ammonia-nitrogen is an energetically efficient inorganic nitrogen source that has been found to be a favorable nitrogen form for Cyanobacteria, as well as other phytoplankton, followed by nitrate, nitrite, and atmospheric nitrogen (Oliver & Ganf, 2000; Ferber et al., 2004; Flores & Herrero, 2005).

In addition, Cyanobacteria have a lower half-saturation constant for N uptake, which makes Cyanobacteris very competative when N is limited. Maximum growth rates and half-saturation constant (Ks) for uptake of different forms of N vary among Cyanobacterial genera (Table 1). For example, *Anabaena flos-aquae* can use NH_3-N, NO_3--N, and urea as a nitrogen source (Gu & Aleksander, 1993). The Ks for ammonia has the lowest value in comparison to Ks for nitrate and urea. *Anabaena flos-aquae* can grow faster when NH_4^+-N is present, but slower with NO_3^--N, and urea. However, Ks for N uptake remain relatively lower than the Ks constants of other phytoplankton classes. Lower Ks

constants make Cyanobacteria genera better competitors for nitrogen under N-limited conditions in the water. Halterman & Toetz (1984) found *Anabaena* sp. to have the lowest Ks for nitrate uptake among 18 phytoplankton species. *Microcystis* sp have a lower half-saturation constant for ammonium uptake than the green algae *S. quadricauda* (Watanabe & Miyazaki, 1996). Among N_2-fixing Cyanobacteria, *Apnanizomenon* sp. has a lower Ks than *Anabaena* (De Nobel et al., 1998). Low Ks of Cyanobacteria for nitrogen give them competive advantages over other phytoplankton species (Tilman, 1982; Grover, 1997).

2.7.2. Nitrogen fixation (N_2-fixation)

Nitrogen fixation refers to the conversion of nitrogen gas (N_2) to ammonia by an enzyme called nitrogenase (Brezonik, 1973). The nitrogenase enzyme catalyzes the reduction of N_2 gas into bioavailable ammonia (NH_3), and involves various ATP-generating processes in providing the high activation energy required to break the triple bond of N≡N (LaRoche & Breitbarth, 2005):

$$8H^+ + N_2 + 8e^- + 16ATP \rightarrow 2\ NH_3 + H_2 + 16ADP + 16P$$

From the above reaction it can be seen that N_2-fixation is an energy intensive metabolic process (16 molecules of ATP are needed to produce two moles of NH_3) , while assimilation of external nitrite across the cell membrane before reduction to ammonium requires 1 ATP (Flores, 2005; Stal, 2009). Although expensive, N_2-fixation is probably the most advantageous mechanism Cyanobacteria have to compensate nitrogen requirements when N is limited. Under N-limited conditions, Cyanobacteria produce heterocysts, specialized non-vegetative cells in which N_2-fixation takes place. Studies found that heterocysts differentiate from vegetative cells 12-20 h after the total inorganic N in the water column decreased to a concentration of 0.004 – 0.02 mg/L (Holl & Montoya, 2005; Campbell et al., 2007). N_2-fixation in heterocysts occurs parallel to photosynthesis in

vegetative cells during daytime. N_2 fixed in heterocyst is transported to adjacent vegetative cells, and through the same channels, carbon metabolites produced in vegetative cells are transported to heterocyst (Wolk, 1996). Heterocysts frequency is an indicator of the N_2-fixation capacity (Wolk, 1996; Kumar et al., 2013). Heterocyst can account for approximately one in ten cells within an *Anabaena variabilis* filament (Thiel & Pratte, 2001).

Although N_2-fixation has been used to explain cyanobacterial dominance in eutrophic lakes and reservoirs, N_2-fixation might not be the only N source used to compensate N requirements for cyanobacterial growth. For example, despite the increased heterocists frequency of dominant N_2-fixers in Lower Karori Reservoir, New Zealand, the heterocysts maximum preceded the increase of Cyanobacteria vegetative cell, but decreased during the following increase of the biomass and bloom of *Anabaena planktonica* (Wood et al., 2010). N_2-fixing supported the growth of N_2-fixers when TDIN was below 0.10 mg/L, but more likely switched to energetically cheaper nitrogen (ammonium) uptake when the ambient combined nitrogen in water increased above 0.2 mg/L. In another study, it was found that when N_2-fixing Cyanobacteria contributed 81-98% of phytoplankton composition, N acquired via fixation was just about 9% compared to the more than 80% of ammonia uptake (Ferber et al, 2004).

2.7.3. Phosphorus (P) requirements for Cyanobacteria growth

N_2-fixing Cyanobacteria species have a higher half-saturation constant for P compared to diatoms (Tilman et al., 1982), green algae (Sommer, 1986, Shafic, 1991, Spijkerman & Coesel, 1996), and dinoflagellates (Berman & Dumbinsky, 1985) (Table 1). As described earlier, Cyanobacteria are poorer P-competitors as compared to other phytoplankton groups (Fogg et al, 1973; Smith, 1983). In addition, *Aphanizomenon* sp. have

a higher half-saturation constant for P in comparison with other N_2-fixing species, such as *Nodularia* sp. (Degerholm et al., 2006) and *Anabaena* sp. (DeNobel et al, 1997), which makes *Aphanizomenon* sp. less competitive when P is the limiting nutrient.

2.7.4. Storage strategy of phosphorus

Cyanobacteria also can store P as polyphosphate reserves (Simon, 1987) when P is in excess (Sandgreen, 1991). The stored products give Cyanobacteria opportunities to survive for at least 12 hours without changes in cell development and physiology, when P becomes the limited factor in the surface layers (Collier & Grossman, 1992). The amount of P stored enables Cyanobacteria to perform 4-8 cell divisions (Chorus & Mur, 1999).

On the other hand, prolonged P limitation could result in a decreased growth, reduced cell P content, and suppressed heterocyst formation. Decreased heterocyst formation would result in a reduction in N_2-fixation, which would result in decreases cellular N content (Layzell et al., 1985; Thompson et al., 1994). Therefore, P-limitation would let some Cyanobacteria lose the most advantageous ability to fix N_2. In addition, the nutrient deprivation of N and P may cause degradation of Chl-*a* and discoloration of cells (Collier & Grossman, 1992).

2.7.5. Buoyancy regulation

Many Cyanobacterial species have a physiological ability to regulate their buoyancy which is an ecologically important competitive mechanism enabling them to adjust vertical position in the water column. The buoyancy regulation depends on the extent to which the lift provided by gas vesicles contradicts cellular density (Reynolds & Walsby, 1975). Regulation of buoyancy enables Cyanobacteria to migrate vertically and access spatially separated resources, light, and nutrients (Ganf & Oliver, 1982). The migration upward through the water column Cyanobacteria will benefit by remaining longer in the productive

euphotic zone (Reynolds & Walsby, 1975). On the other hand, migration allows Cyanobacteria to escape high light intensity at the surface water, which may damage pigments and the photosynthetic system (Pierson et al., 1994). The migration downwards is especially important during the summer when nutrient concentrations are rapidly reduced on the surface due to stratification (Konopka, 1981).

Gas vesicles (vacuols) produced by Cyanobacteria reduce the cell mass density below water density (Walsby, 1972, 1978). Buoyancy adjusts by changes in gas vacuolization or regulation by the balance between accumulation and reduction of carbohydrates reserves. Increasing of turgor pressure can result in gas vesicles collapse. The gas vesicles production should proceed at a rate equivalent to cell growth and division to maintain buoyancy, otherwise gas vesicles will be "diluted" by cell growth (Oliver, 1994) and increase in carbohydrate content of the cell (Walsby, 1972). The rate of gas vesicle production may decrease or cease at high irradiance, which leads to buoyancy loss during the daytime, while at night cells regain buoyancy (Utkilen et al., 1985).

In the euphotic zone, as a result of photosynthesis, cells produce and store large quantities of carbohydrates, such as polyphosphate granules, which are denser than the water ($\rho \sim 1550$ kg/m^3) (Chorus at al., 1999). Carbohydrates act as ballast, causing filaments or cells to sink at a rate dependent upon their colony size and density of the cell. By sinking, colonies move out of the euphotic zone into the deeper, dark water layers, where they use their carbohydrates during respiration. They then become buoyant again and return floating to the surface (Walsby et al., 1995).

The calm periods, with less wind, usually benefit accumulation of Cyanobacteria in the surface water layers during the day, forming surface scums along leeward shores and in sheltered bays (Walsby et al., 1991). Turbulence, on the other hand, tends to disperse

phytoplankton cells into the water column and its distribution will depend on the degree of turbulence and speed with which the phytoplankton cells rises. In addition, nutrient limitation in lake and reservoirs, as demonstrated in several experiments, could cause buoyancy losses by Cyanobacterial species (Reynolds & Walsby, 1975; Konopka, 1982; Brookes et al., 1999). At extremely low N concentrations, N-limitation could affect buoyancy regulation of *Microsystis flos-aque* by restricting production of proteins and vescles resulting in loss of buoyancy (Chu et al., 2007). Under N-limited condition (close to 0 µM) cells suffer from a dilution in gas vesicle and increase carbohydrate content, which resulted in a loss of buoyancy (Brookes & Ganf, 2001).

2.8. Artificial Aeration: Purposes and Effectiveness

Artificial aeration is a common management technique employed in thermally stratified and oxygen depleted lakes with the main purpose to increase DO (DeMoyer et al., 2003; Gafsi et al., 2009). Artificial aeration is commonly achieved by releasing compressed air from perforated pipes or diffusers installed on the bottom of a lake or reservoir. Released air creates a rising plume of bubbles, and at the same time mixes hypolimnetic cold water with epilimnetic warm water. This results in decreasing of summer water temperatures on the surface and increasing of water temperatures near the bottom (Schladow & Fisher, 1995). Elimination of stratification enables better vertical circulation (mixing) of the water column and improves diffusion of the oxygen from the surface oxygenated layers. In addition to eliminating thermal stratification and promoting circulation, bubbling air directly increases the DO in water column.

2.8.1. Effectiveness of artificial aeration on phosphorus release from sediments

Several studies showed the importance and effectiveness of oxygen concentrations to reduce P release from sediment. Beutel et al. (2007) used laboratory scale reactors to

confirm that maintenance of the oxygenated sediment-water interface would inhibit sediment release of P. SRP flux under anaerobic condition was 10-29 mg P/m^2/d. When DO concentration increased to 9 to 10 mg/L by aeration SRP flux reduced to 3.6 mg P/m^2/d (Beutel et al., 2007). Anoxic sediments also resulted in release of reduced metals in the water column. The data also show that, while water was aerated, Mn concentrations decreased from 0.11 mg/L almost to zero, while Fe content decreased from 0.25 mg/L to about 0.10 mg/L. Based on these experimental data the rates of phosphate, iron and manganese released from sediments could be reduced by maintaining a well-oxygenated sediment-water interface (Beutel et al., 2007).

Christophoridis and Fytianos (2006) focused their study on the impact of physicochemical conditions (pH, redox potential, Fe, Mn, Ca, and Al concentrations) on sediment P release in Lake Volvi and Lake Koronia in Northern Greece. Under oxic conditions (redox potential of +300 mV) and pH 8 in Lake Volvi, concentration of P decreased from 0.10 mg/L to close to zero mg/L at rate <0.005 mg P/m^2/day. The formation of a brown-yellow layer on the surface of the sediments of Lake Volvi indicated formation of iron-hydroxide, which prevented further P release from the sediments. In Lake Korona, oxic condition reduced P release rate from 1.58 mg P/m^2/day under anaerobic condition (-200 mV) to 0.200 mg P/m^2/day. However, P release was not eliminated and no formation of an oxidized layer was observed. The authors also report that Lake Korona has a higher water and organic content than Lake Volvi. The results suggest that higher oxygen content resulted in a decrease of phosphorus release from sediments, however, the release was not eliminated when higher organic content is present. The authors believed that increase of biological activity was the main factor in P release in Lake Korona.

Artificial aeration applied in Sweeney Lake, Minnesota, resulted in reduction of TP from 1.20 mg/L to 0.10 mg/L (Hanson & Austin, 2012). The reduction was significant; however, the concentration was still high and remained relatively constant during operation of the aeration. These results suggest that although reduced, the release of P was not eliminated by operation of aeration. The authors explained that the P release was because of an insufficient increase of DO on the bottom of the lake. Hanson and Austin (2012) report that DO hardly exceeded 2 mg/L and probably was not high enough to decrease sulfate reduction. Further release of P was explained by the mechanism of Fe-S redox chemistry. Results from long-term experimental studies of hypolimnetic aeration (Gächter & Wehrli, 1998) and artificial oxygenation (Moosmann et al., 2006; Schauser & Chorus, 2007) reveal that aeration had a limited effect on sediment-P release.

2.8.2. Effectiveness of artificial aeration on nitrogen release from sediments

A field study conducted to confirm that oxygenation using hypolimnetic aeration was able to reduce hypolimnetic ammonia concentration without significantly affecting stratification (Beutel et al., 2007). Results show that the ammonia release was higher under anaerobic condition. On the other hand, nitrate was released at a higher rate under aerobic condition, whereas when condition was changed to anaerobic nitrate concentration decreased rapidly. When added together ammonia and nitrate, expressing Total Nitrogen (TN) is considered, results showed a higher sediment nitrogen loading releasing rate under aerobic conditions than under anaerobic conditions.

Results from a study, where experimental chambers with sediment from a Danish lake was used to investigate oxygen regulation on nitrification and denitrification, it was found that under anoxic conditions, ammonia fluxes were around 80 mg-N /m^2/d (Rysgaard et al., 1994). On the other hand, fluxes decreased to 30 mg-N /m^2/d at 5 mg/L DO, and 10

mg- mg-N /m^2/d at 10 mg/L DO (Rysgaard et al., 1994). Results also show that under higher oxygen concentrations the nitrate-nitrogen release rate increased.

Experimental results suggest that aeration more likely would stimulate nitrification, which would result in a reduction of ammonia from lakes and reservoirs. However, aeration likely would not result in a reduction nitrogen loading from sediments.

2.8.3. Effect of artificial aeration on phytoplankton seasonal succession and Cyanobacteria growth.

It is generally accepted in freshwater ecology that primary productivity is limited by the availability of P, and management and decision-making efforts in freshwater ecosystems have been focused on controlling and on reducing P loading (Havens & Walker, 2002; Sterner, 2008; Schindler, 2012). Since eutrophic lakes are associated with frequent dominance and blooms of Cyanobacteria (Vollenweider & Kerekes. 1982; Paerl et al, 2011), several studies have focused on using artificial aeration as a method to control Cyanobacteria growth.

Artificial aeration has been a successful method for reducing problematic blooms of scum-forming *Microcystis* sp. in highly eutrophic Lake Nieuwe Meer, in the Netherlands (Visser et al., 1996). The lake was mixed using artificial aeration to prevent growth of *Microcystis sp.*. Based on preliminary measurements on floating velocity of *Microcystis sp.*, artificial aeration was designed to create a mixing rate velocity of water higher than flotation velocity of *Microcystis sp.*, thereby creating a condition in which buoyancy regulation was no longer a competitive advantage for Cyanobacteria (Visser et al., 1996). Increased mixing of water, due to aeration, resulted in nearly equal vertical distribution of Cyanobacteria and other phytoplankton groups. Buoyancy regulation was reduced only at sites close to aerators where the cells were dispersed deeper in the lake, but buoyancy was

still an advantage away from aerators. In addition, the authors reported that phytoplankton summer populations shifted to flagellates, green algae (mainly *Scenedesmus*), and diatoms (mainly *Stephanodiscus* and *Cyclotella*). Results also indicate that abundance of N_2-fixing *Aphanizomenon* increased when lake was aerated. The authors reported that aeration did not affect TP concentrations. However, aeration increased Chl-*a* concentrations as determined per square meter (Visser et al., 1996). Higher Chl-*a* and changes in phytoplankton population suggested that aeration likely changed nutrient concentrations; however, effect of aeration on nutrients was poorly discussed. Artificial aeration controlled Cyanobacterial blooms, non-N_2-fixing species, to some extent and it was less successful for *Aphanizomenon*.

Heo and Kim (2004) also reported replacement of Cyanobacteria by diatoms. Based on a study conducted to evaluate aeration in reduction of Cyanobacteria blooms in a drinking-water reservoir in South Korea, the authors reported that circulation created by aeration resulted in a homogeneous temperature and DO concentration in the lake. The results show that the Cyanobacteria growth was reduced and replaced by diatoms. However, Chl-*a* increased in the four-year period of operation of destratification (Heo & Kim, 2004). The effect of destratification on phytoplankton community changes depended on the change in mixing of the water column and competition for the light between phytoplankton species. Authors commented that destratification has no effect on reducing higher TP concentrations. TP concentrations continue to be above 0.02 mg/L in summer months, when destratification was in operation (Heo & Kim, 2004). The authors assumed that the internal P-loading probably was reduced due to increased redox potential at the sediment surface, caused by aeration. However, TP in the lake followed similar higher concentrations in summer. The authors believed that increased TP concentrations were due

to increased external loading during the monsoon season. (Heo & Kim, 2004). Although Heo and Kim (2004) commented that, the artificial mixing in the reservoir may extend natural spring mixing, when nutrient concentrations are high. However, the authors did relate nutrient concentrations to the observed higher Chl-*a*, caused by destratification.

Artificial aeration was also employed in the North Pine Reservoir, Australia to increase DO concentrations and to reduce sediment nutrient release (Antenucci et al., 2005). The study was conducted to investigate the effect of artificial destratifaction on phytoplankton and more specifically on N_2-fixing C*. raciborskii*. Results show that abundance of diatoms and cyanobacteria increased due to aeration, but no significant differences were observed for Chlorophytes and dinoflagellates. Based on correlation analyses of TP and abundance of dominant Cyanobacteria-*C. raciborskii* and knowledge, the authors concluded that before implementation of aeration *C. raciborskii* dominated because its strong ability compete for P. Turning on of aeration did not changed TP concentration and the dominance of *C. raciborskii.* The authors eliminated N_2-fixing as the main reason of their success because the nitrate (0.49 mg/L) and ammonium (0.19 mg/L) concentrations were relatively too high to cause N_2-fixation. They believed that the dominance *C. raciborskii* over diatoms, under aerated condition, was due to its ability to compete for light in turbid mixed layers (Antenucci et al., 2005). Thereby, the competition for light was a possible factor increasing abundance of *C. raciborskii* under aerated condition (Antenucci et al., 2005). Data of phytoplankton abundance indicated that Cyanobacteria growth increased in time, began earlier, and were sustained.

In a related study, phytoplankton community assemblages in artificially aerated North Pine Reservoir, Australia was compared with two adjacent naturally mixed reservoirs (Burford & O'Donohue, 2006). The results show that there were no major

differences in algal species structure within the three reservoirs, where *Aphanocapsa, Merismopedia, Cyanodiction,* and *C. raciborskii* were dominant species. However, in the artificially aerated reservoir blooms of *C. raciborskii* and *Planktolyngbia* commence earlier, were more severe, and prolonged with a time (Burford & O'Donohue, 2006). Earlier peaks of the dominant genera between naturally and artificially mixed reservoirs suggest that aeration also changed distribution of nutrients over time. However, dominance of *C. raciborskii* was due to: 1) better adaptation to light condition, which made them more successful at reduced light due to mixing and 2) a high uptake rate and storage capacity of P under low concentrations (Burford & O'Donohue, 2006).

Failure of artificial aeration to reduce phytoplankton blooms was reported by Sherman et al. (2000) and Becker et al. (2006). Sherman et al. (2000) reported reduction of sediment nutrient release (TN and TP) in aerated lakes, but that did not result in a reduction in phytoplankton biomass. The authors explained that the artificial destratification was not strong enough to eliminate thermal stratification. In his research, Becker et al. (2006) reported that although the *Microcystis* population was reduced, diatoms and chlorophytes become more abundant. Similarly, to the research conducted by Visser et al. (1996), destroying of buoyancy regulation due to mixing caused by aeration was the main cause of reducing of *Microcystis* abundance. However, the authors did not clearly explain the causes that triggered the shift in phytoplankton species dominance.

CHAPTER 3. STUDY SITE AND METHODS

3.1. Study Site

Heinrich-Martin Dam (HMD) reservoir, located in LaMoure County, ND, was used as the site for this study. The reservoir was constructed on an unnamed tributary of the James River in 1965 (Wax, 2008). The HMD was constructed for recreational purposes, such as fishing, swimming, and camping (Kratz, 2007), and is managed by the North Dakota Game and Fish Department (NDGF). The HMD has a surface area of 0.08 km^2 with a maximum depth greater than 10 m and mean depth of 4.30 m. The outflow of water from the HMD impoundment is regulated by a control structure (Figure 4) to maintain water level relatively constant. Estimated drainage area is approximately 11.27km^2. The soil consists of Buse-Barnes loams and Barnes-Svea loams. The land use is agricultural including small and row grains, such as soybean and corn. (Overmoe, 2008).

In summer months, the HMD impoundment experiences thermal stratification, low DO concentrations, and frequent algal blooms. Artificial aeration was installed with the intention to increase DO concentration and to improve habitats for fish. Aeration was achieved by installing a 45 m section of 1.2 cm diameter aeration tubing connected to a ¾ horsepower, oil-less piston air compressor (Kratz, 2007). The diffusers were installed in the deepest part of the reservoir (Figure 4). Figure 5 shows air bubbles from the diffuser.

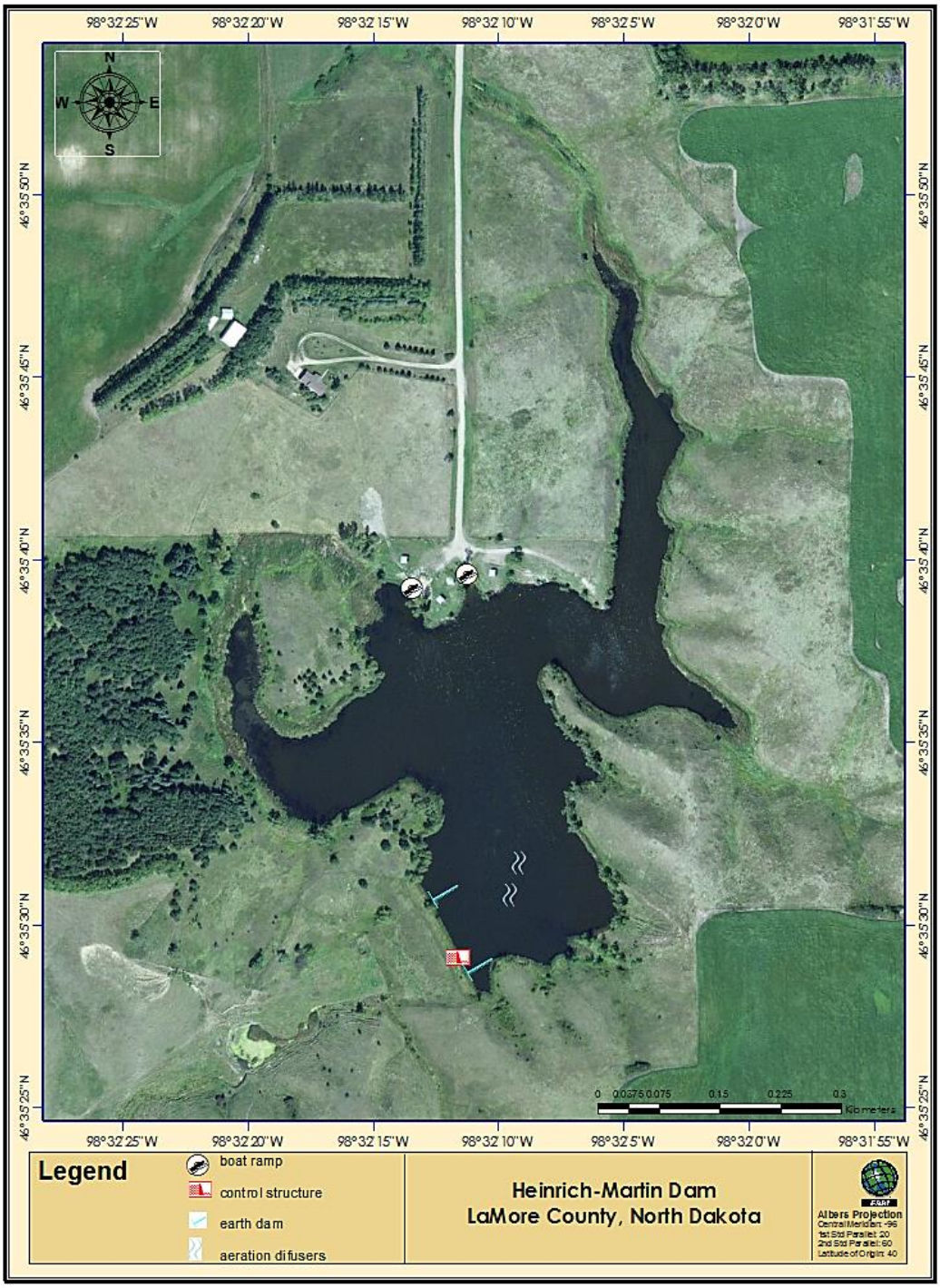

Figure 4. Heinrich-Martin Dam aerial map

Figure 5. Air bubbles on the surface of the HMD generated from aeration

3.2. Sampling Duration and Frequency

To evaluate the impact of artificial aeration on water quality and phytoplankton growth, water samples were taken under aerated and non-aerated conditions during the summer growing seasons of 2010 (June 4th until October 15th) and 2011 (June 30th until November 8th). In the summer of 2010, aeration was operated continuously. During the sampling period of 2011, aeration was stopped from July 13 to September 1, due to operational decisions by NDGF.

Based on data from previous research (Overmoe, 2008) it was evident that spatial variations in nutrient concentrations were minimized by aeration and no rapid changes in parameters was expected, the field measurements and water sampling under aerated conditions were taken on a biweekly basis. When aeration was turned off, more changes in water quality parameters and phytoplankton growth were expected. Therefore, more frequent sampling, once a week, was carried.

3.3. Sampling Locations

To determine effects of artificial aeration on horizontal and vertical distribution of nutrients (N and P) and phytoplankton, water samples were taken from four sampling locations (Figure 6). The sampling sites A, B, C and D were chosen with consideration of water depth and influence of the artificial aeration. A detailed description of the four sites is presented in Table 2.

Table 2. Sampling sites description

sampling site	geographic coordinates		water depth (m)	site description
	longitude	latitude		
A	46 35 513 W	98 32 178 N	10	close to the air diffusers, affected by the mixing effects of aeration
B	46 35 578 W	98 32 125 N	6	less affected by the aeration, close to the shoreline
C	46 35 567 W	98 32 271 N	4	not affected of aeration, closed edge in reservoir
D	46 35 618 W	98 32 078 N	5	not affected of aeration but near the inlet of the reservoir

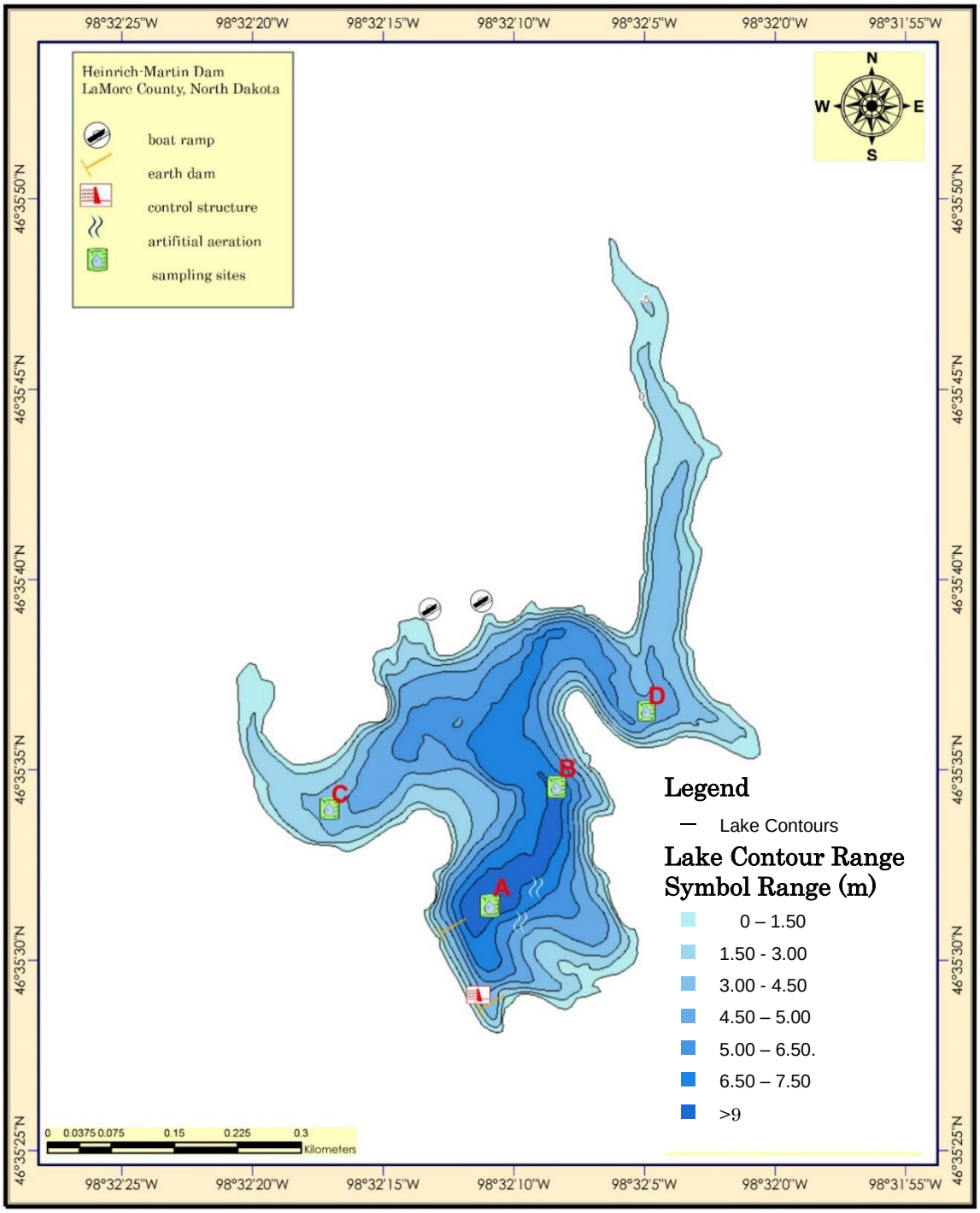

Figure 6. HMD contour map with sampling sites. A, B, C, and D sampling stations.

3.4. Sampling Depths.

To determine effect of artificial aeration on nutrients (N and P) and phytoplankton (Chl-*a* and biovolume) vertical spatial distribution water samples were taken at the following depths:

Table 3. Sampling parameters and sampling sites, 2010 and 2011.

parameter	2010		2011	
	depth	Sites	depth	Sites
Nitrogen Phosphorus	0.50 m (Surface), Secchi depth, 2×Secchi depth, 0.50 m from the bottom	B	0.50 m (Surface), Secchi depth, 2×Secchi depth or 1.0 m below thermocline* 0.5 m from the bottom (0.5B), 1.5 from the bottom (1.5B)	A, B
			Secchi depth	C D
Chl -*a*	0.5 m (Surface), Secchi depth, 2×Secchi depth, 0.5 m from the bottom	A, B, C, D	0.5 (Surface), Secchi depth, 2×Secchi depth or 1.0 m below thermocline* 0.5 m from the bottom (0.5B), 1.5 from the bottom (1.5B)	A, B, C, D
Phytoplankton	0.5 m (Surface), Secchi depth, 2×Secchi depth, 0.5 m from the bottom	A, B, C, D	0.5 (Surface), Secchi depth, 2×Secchi depth or 1.0 m below thermocline* 0.5 m from the bottom (0.5B), 1.5 from the bottom (1.5B)	A, B, C, D

Note: * when reservoir is aerated the samples were taken at 2×Secchi depth, when reservoirsamples were taken at 1.0 m below the thermocline

- **Secchi depth (SD)**. SD is a function of the absorption and scattering of light by particles (algae, sediments, and detritus) and dissolved substances in the water. Secchi disk is a visual measurement that provides a numerical value of the water quality and is used to determine the depth at which light penetrates in the water body (Preisendorfer, 1986). Light availability affects rates of the photosynthesis and thereby the growth and distribution of the phytoplankton.
- Two times Secchi disk depth (2×Secchi depth) is an approximate estimation

of the maximum depth of euphotic zone at which 1% of the incident light penetrates (Koenings & Edmundson, 1991).

- 0.5 and 1.5 m from the bottom depths were chosen to determine the vertical nutrient gradient and the extend at which phytoplankton would be distributed.

3.5. Chemical Parameters

Water samples for chemical (nutrient) analysis (TDIN, SRP, TN, and TP) were taken with a vertical Van-Dorn water sampler. The laboratory analyses for all nitrogen and phosphorus species were conducted within 24h following Standard Methods for the Examination of Water (American Public Health association (APHA), 1995) at NDSU Environmental laboratory.

- **Ammonia nitrogen (NH_3-N)** - 4500-NH_3 Phenate Method
- **Nitrate-nitrogen (NO_3-N)** - 4500-NH_3 Nitrate Electrode Method
- **Nitrite-nitrogen (NO_2-N)** – 4500-NO_2 UV Spectrophotometric Method
- **Total nitrogen (TN)** – 4500-N Persulfate Digestion/Nitrate Electrode Method
- **Soluble Reactive Phosphorus (SRP)** – 4500-P Ascorbic Acid Method
- **Total Phosphorus (TP)**– Acid Digestion/Ascorbic Acid Method

3.6. Biological Parameters

The samples for **Chl-*a*** and biovolume determination were taken during both sampling events from all described earlier sampling depths, at each of four sites.

- **Chlorophyll-*a* (Chl-*a*).** Water samples for Chl-*a* extraction were taken with a vertical Van Dorn water sampler and filtered in the field through Whatman GF/F-0.7 µm pore size glass fiber filters. The pigment ethanol extraction method (Lorenzen, 1967; Sartory et al., 1984) and spectrophotometric

determination were performed within 24 h after sampling in Environmental Lab in NDSU.

- **Phytoplankton identification and enumeration** 500 ml water samples for phytoplankton identification, enumeration, and biovolume determination analysis were preserved with Lugol's acid solutions on field. After two weeks of sedimentation, the supernatant was removed. Concentrated samples were transferred in smaller 50 ml containers. Phytoplankton species were counted and identified in 1 ml, Sedgewick-Rafter chamber under Inverted Microscope (LeGresley & McDermott, 2010).
- **Phytoplankton Biovolume determination (Biovolume).** For biovolume determination *ImageProPlus 5.0* image analysis, software was used following developed for this study Methodology for phytoplankton biovolume estimation. The biovolume of each phytoplankton unit (cell, colony or filament) was determined by multiplying, the unit volume by the abundance of these unit in the sample. The biovolume of each unit was determined by applying one of the three developed methods: 1) area and depth method, 2) cross section area and length method, and 3) biovolume based on commonly accepted geometry. Detailed procedure for phytoplankton biovolume determination is presented in APPENDIX D).

3.7. Onsite Monitoring Parameters

A Yellow Spring Instruments (YSI) multi-probe sonde was used to monitor the following water quality parameter during each sampling event: water temperature, conductivity, and DO. Readings were taken at the surface (0.5 m depth), 1.0 m depth and then every meter to the bottom. Secchi depth also was measured at each sampling site.

3.8. Statistical Analysis

Analysis of variance (ANOVA) is a statistical procedure used to test the degree to which the means of three or more groups differ. The one-way ANOVA test has a null hypothesis (H_0) that all the group population means are the same. The alternative hypothesis (H_A), on the other hand, is that at least one of the means is different (McClave & Sincich, 2009).

H_0: $\mu_1 = \mu_2 = \ldots \mu_k$

H_a: means are not all equal.

In statistical hypothesis testing, a p-value (a probability) is used to determine whether the sample provides strong evidence against the null hypothesis. The test statistic in ANOVA is the F ratio, or F test for equality of factor level means (Neter et al., 1996). The p-value (observed significance level) is the probability, assuming that H_0 is true, of observing a test statistic (as extreme or more extreme than the one calculate. If the p-value is less than the predefined significance level, the null hypothesis is rejected, indicating that the sample gives reasonable evidence to support the alternative hypothesis. The choice of significance level is arbitrary. Conventionally the 5% (less than 1 in 20 chance of being wrong), 1% and 0.1% (p-value < 0.05, 0.01 and 0.001) levels have been used. More often however, it is usually 5% used (McCleery et al., 2007). In this study, the one-way ANOVA analysis was performed to test the effect of artificial aeration on nutrient and phytoplankton distribution between sampling depths and throughout sampling sites. In this study, the null hypothesis assumes that the nutrients (concentrations) or phytoplankton (Chl-*a* concentrations and biovolume) are equally distributed at all sampling depths or among sampling sites. The alternative hypothesis is that at least one of the sampling sites/sampling depths means differ from the others. For this research, a p-value of

less than 0.05 was used to determine statistical significance. Tukey's (HSD) test is a post-hoc test, which is performed after an ANOVA test. While ANOVA analysis reveal whether groups in the samples differ, it cannot tell the researcher which groups differ. The purpose of Tukey's HSD test is to determine which groups in the sample differ.

Wilcoxon Mann-Whitney's (WMW) is the non-parametric analog to the two-sample t-test for independent populations and is used when no assumptions are made about the underlying distributions of the data. However, the assumptions that the observations are randomly obtained and that within each sample the observations are independent and identically distributed still must be met. An advantage of this test is that the two samples under consideration may not necessarily have the same number of observations. In WMW the values are ranked from low to high. The smallest number gets a rank of 1. The largest number gets a rank of n, where n is the total number of values in the two groups. The observed rank sum, W, of group 1 (or group 2) is found. All possible permutations of the ranks for group 1 and group 2 are found and for each permutation of the ranks, the rank sum for group 1 is calculated, these values are used to calculate a test statistic, and the p-value is determined. The null hypothesis is that the distributions of both groups are identical and the alternative hypothesis is that the two distributions differ with respect to the median. In this study WMW test was used to compare the differences between the depth-weighted averaged nutrient concentrations (TDIN, SRP, TN, and TP) and phytoplankton (Chl-*a* and biovolume) data between period without aeration in 2011 with the similar period in 2010 when the lake was aerated.

All statistical analyses were conducted using the SAS statistical program.

CHAPTER 4. IMAPACTS OF ARTIFICIAL AERATION ON SEDIMENT NUTRIENT RELAEASE AND PHYTOPLANKTON GROWTH

4.1. Abstract

Use of artificial aeration to eliminate thermal stratification in deep lakes has been a common management practice for improving water circulation and oxygen transfer, and reducing nutrient, especially phosphate (P), release from sediments. Reducing sediment P-release was believed as a viable method for reducing phytoplankton growth where sediments are the main nutrient source. However, long-term lake studies showed inconclusive results on the effectiveness of aeration on controlling internal P loading and phytoplankton growth. To evaluate the impact of artificial aeration on nutrient release and phytoplankton growth, water samples were taken from a small reservoir under aerated and non-aerated condition during growing seasons of two consecutive years (2010 and 2011) for nitrogen (N), P and Chlorophyll-*a* (Chl-*a*) analyses. Results showed that aeration was able to reduce sediment P release by nearly 50%. Increased oxygen levels on the bottom of the lake inhibited release of metal-bound phosphate. However, P release from sediments was not eliminated. Sediment P release continued when the impoundment was aerated, indicating that biological degradation of organic matter is a mojor mechanism of sediment nutrient release. In addition, mixing effect of aeration made nutrients more available resulting in more phytoplankton growth.

4.2. Introduction

Eutrophication driven by excessive input of nitrogen and phsposphrus (N and P) is one of the most serious environmental challenges worldwide. Major water quality changes and concerns associated with eutrophication include excessive phytoplankton blooms and related decreased water transparency, offensive odor and taste from live and dead

phytoplankton biomass, and toxins released by some Cyanobacterial species. Respiration and decomposition of dead phytoplankton biomass cause a large diurnal variation of dissolved oxygen (DO) and even complete consumption of DO near the bottom of the water bodies. Lack of oxygen could causes fish kill and degrading of the aesthetic value of water bodies. Thereby, phytoplankton blooms due to eutrophication are a threat for water quality and designated beneficial uses of lakes and reservoirs, such as drinking water supply, recreation, and fishery.

In eutrophic lakes, organic rich sediment is a huge reservoir for P, N and other nutrients for phytoplankton growth; however, it is generally accepted in freshwater ecology that primary productivity is limited by availability of P (Smith at al, 1983; Havens & Walker, 2002; Søndergaard et al, 2003; Sterner, 2008; Schindler, 2012). When P is released from sediments, it becomes available for phytoplankton growth (Søndergaard, 2001, 2003). Therefore, management and decision-making efforts in eutrophic freshwater ecosystems have been focused on reducing internal loading of P (Paerl et al., 2011; Schindler, 2012).

Artificial aeration is a commonly employed method with a primary purpose to destratify water column in summer and to increase DO levels at the bottom of the lakes (DeMoyer et al., 2003; Gafsi et al., 2009). For decades, it has been accepted that the oxic condition at the sediment-water interface would promote precipitation of metal-bound phosphorus in the sediments (Mortimer, 1941, 1942; Einsele, 1936; Boström et al., 1988). Another mechanism of P is from biological decomposition of organic matter under in sediment. Biological release of P may happen under bothanaerobic and aerobic conditions (Deinema et al., 1985; Wentzel et al., 1991). A number of studies revealed that aerobic decomposition of organic matter is faster than anaerobic decomposition (Kristensen et al., 1995; Geurts et al., 2010).

Numerous short-term and bench studies demonstrated that oxygenation due to aeration could be a successful technique in reducing sediment P release (Nowlin et al., 2005; Beutel et al., 2007; Wu et al., 2014). However, field data from long-term studies showed that aeration had limited or no effect on sediment P release (Gächter & Wehrli, 1998; Christophoridis & Fytianos, 2006; Moosmann et al., 2006; Hanson & Austin, 2012). It is still unclear how aeration affects the internal P loading or if it causes a long-term decrease in P release. The results from studies in which artificial aeration was used to reduce phytoplankton growth, especially Cyanobacteria growth, are even more inconclusive. Several studies report reduction in Cyanobacterial growth as a result of aeration; however, the same studies report an increase in Chl-*a* concentration and population's composition shifts to flagellates, green algae, and diatoms. These changes in phytoplankton composition was believed to a result of increase in mixing, through which buoyancy regulation of Cyanobacteria was destroyed (Visser et al, 1996; Jungo et al, 2001) or became less competitive under lower light intensity (Heo & Kim, 2004). The results from two related studies reported that instead of decreasing of Cyanobacteria growth aeration increased Cyanobacterial abundance and prolonged their period of growth (Antenucci et al, 2005; Burford & O'Donohue, 2006). Although in all these studies the increases of overall Chl-*a* content suggest that the aeration changed the nutrient concentrations for phytoplankton growth, none of these studies has addressed the effects of artificial aeration on N and P release and nutrient availability for phytoplankton growth.

In North Dakota according to the water quality assessment report from 2012, 45% of assessed lake and reservoirs are eutrophic that makes eutrophication serious water quality concern in North Dakota. To increase DO concentration in the hypolimnion and increase habitat for fish, air diffusers were installed by North Dakota Game and Fish Department

(NDGFD) in a Heinrich-Martin Dam (HMD) impoundment, a small eutrophic reservoir in North Dakota (NDDoH, 2012). Prior to installation of aeration, the reservoir experienced summer thermal stratification, low DO concentrations, and frequent phytoplankton blooms. NDGFD also believed that increasing of DO on the sediment-water interface might result in reduction of internal P-loading and phytoplankton growth. Previous research conducted in 2008 to evaluate effectiveness of artificial aeration suggested that the artificial aeration increased DO concentrations and prevented anoxic conditions near the bottom of the lake (Overmoe, 2008). Visual, qualitative observations suggested that high phytoplankton growth continued in the reservoir, but samples for phytoplankton biomass and speciation analyses were not taken. Research is needed to evaluate the impact of artificial aeration on nutrient sediments release and nutrient availability for the phytoplankton growth.

4.3. Methodology

4.3.1. Sampling site, period, and frequency

To evaluate the impact of artificial aeration on nutrient release and phytoplankton growth in the impoundment, water samples were taken from four sample locations during growing seasons of 2010 and 2011. The sample locations, as shown in Figure 6, are spread out in the reservoir and were selected with considerations of water depth, flow pattern in the reservoir, and distances from air diffusors. In 2010, the reservoir was aerated continuously throughout the sampling period, while in 2011 the aeration was turned off for an extended period in the mid-summer (July 13 - September 1, 2010).

4.3.2. Sampling parameters and data processing

DO, water temperature, and conductivity were measured at every meter intervals in depth at each site with a multi-probe YSI sond. To provide a clear picture of temperature, conductivity, and DO variations in depth and over time, data were averaged into three

water layers: surface layer (0.5 to 2.00 m), medium-depth layer (2.00 to 4.00 m), and deep layer (4.00 m to bottom)(Complete temperature data can be found APPENDIX A.).

Water samples were collected for analyses of total nitrogen (TN), total phosphorus (TP), total dissolved inorganic nitrogen (TDIN), soluble reactive phosphorus (SRP) and Chlorophyll-*a* (Chl-*a*). The samples were taken from only Site B in 2010 because, based on data from previous research (Overmoe, 2008), spatial variation in nutrient concentrations were minimized by aeration. Water samples from all sites were collected during 2011. The samples for nutrients and Chl-*a* analyses were analyzed within 24 h after the sampling in the Environmental and Engineering Department Lab at NDSU (a detailed description of sample site, sampling locations and methods are included in Chapter 3). Since the depths at which water samples for nutrients and Chl-*a* analyses were taken varied and were not equally distributed thorough water column, a depth-weighted average (DWA) method was used to calculate average concentrations of nutrients and Chl-*a* (Detailed procedure of DWA is included in APPENDIX D.).

4.3.3. Statistical analyses

One-way ANOVA analyses were conducted to test the differences in vertical (between the depths) and on horizontal (between the sampling sites) distributions of nutrients and Chl-*a*. The Post hoc Tukey's Honestly Significant Difference (HSD) test was conducted after the ANOVA to determine differences between depths. Wilcoxon Mann-Whitney's (WMW) non-parametric test was used to compare the differences between the depth-weighted average (DWA) concentrations Chl-*a* concentrations between non-aerated period in 2011 with the similar period in 2010 when the lake was aerated. All statistical analyses were conducted using the SAS statistical program.

4.4. Results

4.4.1. Impact of artificial aeration on water temperature and conductivity

One of the purposes of artificial aeration is to provide mixing in deep lakes, thereby eliminating or preventing thermal stratification. Water temperature and conductivity in the HMD were measured to evaluate the effectiveness of artificial aeration on elimination of thermal stratification and mixing condition.

4.4.1.1. *Water temperature*

Water temperature data from 2010 and 2011 sampling seasons for Site A, which is located closest to air diffusers and in the deepest part of the impoundment, are shown in Figure 7 and Figure 8, respectively. Variations of water temperature over time during 2010 and 2011, showed similar patterns typical for the temperate lakes. Water temperature increased gradually from spring and early summer, and remained at a relatively stable high level during summer months. After mid-August, water temperatures started and continued to decrease.

In 2010, when the aeration was in operation during the entire sampling period, water temperature was the same throughout the depths of water column at Site A (Figure 7). The ANOVA analysis of water temperatures, measured at each meter through the depth at Site A, confirmed no significant vertical differences of water temperatures ($p=1$, Table E1 APPENDIX E). These results indicate that artificial aeration was effective in eliminating thermal stratification in the deeper part of the impoundment (Site A). Similarly, no significant differences were found between water temperatures measured at each meter across depths at sites B ($p=0.99$), C ($p=0.99$), and D ($p=0.97$) (Data are showne in Tables E2, E3, and E4, respectively.). These results indicate that uniform vertical distribution of water temperatures occurred in all sampling sites during the entire sampling period in 2010.

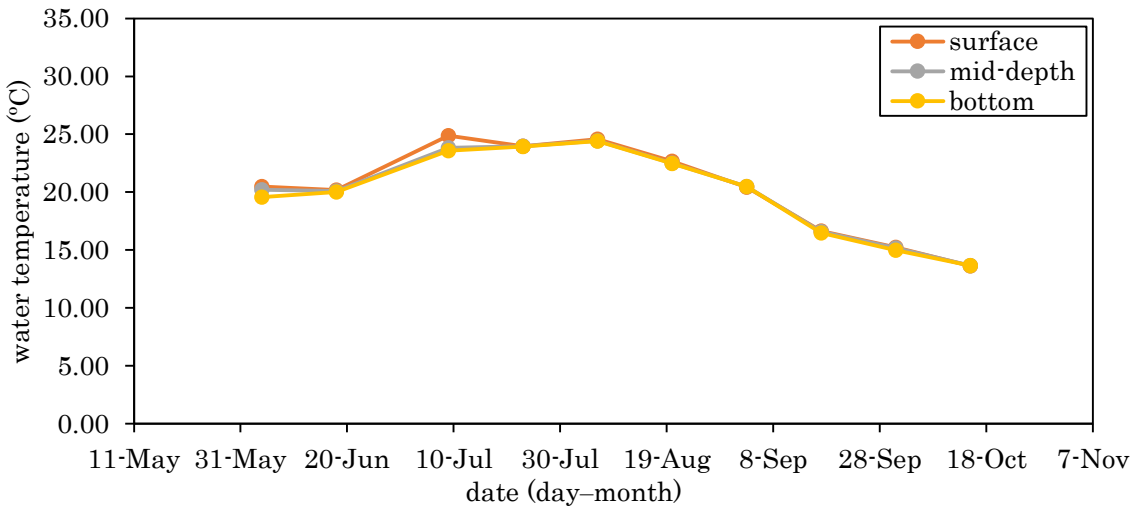

Figure 7. Water temperature at Site A (2010) with aeration during entire period

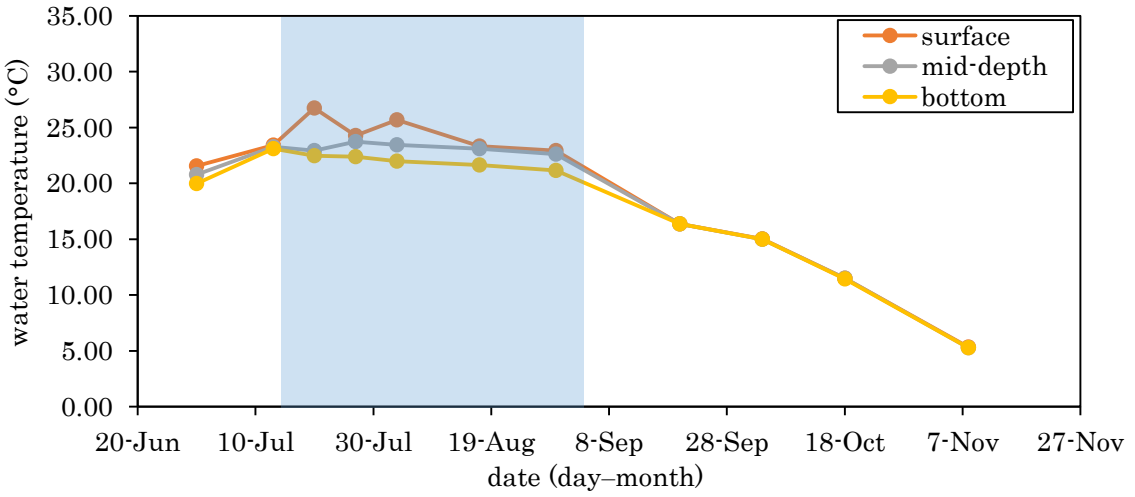

Figure 8. Water temperature at Site A (2011). Shaded area indicate period without aeration.

To compare the horizontal water temperature distribution in 2010, depth-averaged water temperatures and standard deviations (STD) were calculated and are present in Table 4. Based on data in Table 4, depth-averaged water temperatures were similar at all sampling sites with small variations.

Table 4. Depth-averaged water temperatures and Standard Deviations (STD), 2010

date (mo/day/yr)	water temperature (average ± STD),°C			
	Site A	Site B	Site C	Site D
6/4/2010	20.07±0.52	20.00±0.51	19.88±0.26	19.91±0.75
6/18/2010	20.07±0.10	20.06±0.10	20.19±0.14	19.94±0.04
7/9/2010	24.03±0.67	23.89±0.55	24.60±0.52	24.67±1.11
7/23/2010	23.95±0.04	23.95±0.04	23.96±0.08	23.78±0.44
8/6/2010	24.48±0.09	24.47±0.08	24.75±0.46	24.61±0.24
8/20/2010	22.55±0.11	22.53±0.09	22.49±0.14	22.52±0.06
9/3/2010	20.45±0.04	20.46±0.03	20.45±0.23	20.30±0.21
9/17/2010	16.57±0.08	16.56±0.08	16.66±0.15	16.59±0.10
10/1/2010	15.12±0.17	15.10±0.18	15.37±0.03	15.35±0.26
10/15/2010	13.63±0.01	13.64±0.01		

In the sampling season of 2011, due to management and operational reasons, aeration was turned off from July 13th until September 1st (shown as shaded period in Figure 8). One week after aeration was turned off, noticeable difference in water temperatures between the surface and deep layers were observed at Site A (Figure 8). Water temperature on the surface continued to increase, while water temperature in deep layers remained relatively the same. Vertical profile of temperature, as shown in Figure 9, shows establishment of a weak thermal stratification with a thermocline between the depth of 3-4 m at Site A after aeration was turned off. ANOVA confirms significant differences of water temperatures between depths after aeration was stopped ($p<0.01$, Table E20). For the whole period without aeration, results from Tukey's test show that temperatures at the surface layers from 0.5 to 3.0 m were not significantly different (Table E21). However, water temperatures between 3 and 4 meter were significantly different. On the other hand, no significant temperature differences were found between 6 m and the bottom of the reservoir. These results indicate that two layers with different water temperatures were established higher temperatures on the surface (epilimnion) and lower temperatures on the bottom (hypolimnion). Temperature measurements at Sites B, C and D also showed differences between surface and bottom layers, indicating that even in the shallow parts in

the reservoir, the water was slightly stratified naturally (Tables A40, A52 and A64, respectively.).

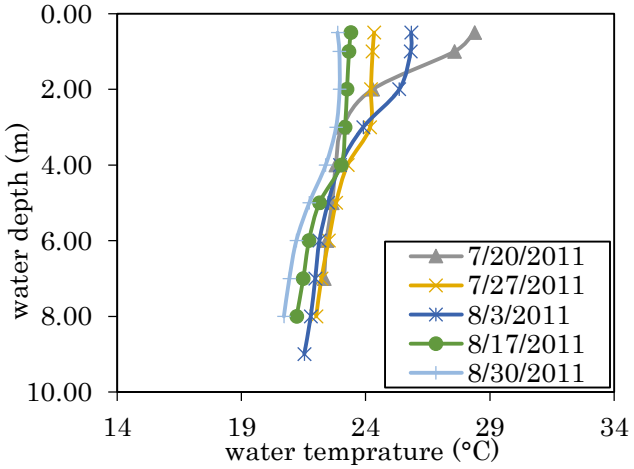

Figure 9. Vertical variation of water temperature at Site A (2011) during non-aerated period

Depth-averaged water temperatures at Site B, C, and D clearly show that water temperatures were similar at all the sites (Table 5). STD were similar at all sites during of the period without aeration (highlighted in bold). After aeration was resumed on September 1st, similar water temperatures at surface, mid-depth, and bottom, as shown in Figure 8, suggest that differences were eliminated and uniform temperature profile was reestablished due to enhanced vertical mixing.

Table 5. Depth-averaged water temperatures and Standard Deviations (STD), 2011

date (mo/day/yr)	water temperature (average ± STD),°C			
	Site A	Site B	Site C	Site D
6/30/2011	20.61±0.77	21.24±1.07	21.85±0.87	21.95±1.10
7/13/2011	23.21±0.18	23.38±0.08	23.35±0.30	23.32±0.15
7/20/2011	**24.19±2.42**	**25.09±2.83**	**25.05±2.37**	**25.31±2.83**
7/27/2011	**23.31±0.96**	**23.63±1.68**	**24.17±0.62**	**24.20±0.55**
8/3/2011	**23.38±1.72**	**24.13±1.68**	**25.14±1.27**	**24.89±1.54**
8/17/2011	**22.53±0.88**	**22.71±0.82**	**23.28±0.25**	**23.54±0.42**
8/30/2011	**22.06±0.92**	**22.28±0.84**	**22.90±0.24**	**22.86±0.17**
9/20/2011	16.35±0.00	16.35±0.01	16.33±0.01	16.34±0.01
10/4/2011	15.00±0.02	15.10±0.02	15.16±0.08	15.14±0.06
10/18/2011	11.46±0.03	11.40±0.13	11.33±0.07	11.39±0.05
11/8/2011	5.30±0.04	5.36±0.15	5.00±0.13	4.88±0.10

Note: bolded values indicate period without aeration.

4.4.1.2. *Conductivity*

Conductivity (specific conductance) is an indirect measurement of amount of dissolved ions in water. Variation of conductivity at Site A during 2010 and 2011 sampling seasons are shown in Figures 10 and 11, respectively. Conductivity increased gradually during the 2010 sampling season (Figure 10) indicating that concentration of dissolved salts increased continuously in the reservoir. Figure 10 also shows that conductivity was basically the same in all three water layers (surface, mid-depth, and bottom), which is confirmed by ANOVA (p=1, Table E5.). These results indicate the water column was well mixed in the deepest part of the reservoir. Similar to Site A, ANOVA results show no significant differences of conductivity between sampling depths at sites B (p=0.97), C (p=0.70), and D (p=0.96) (Tables E6, E7, and E8, respectively.).

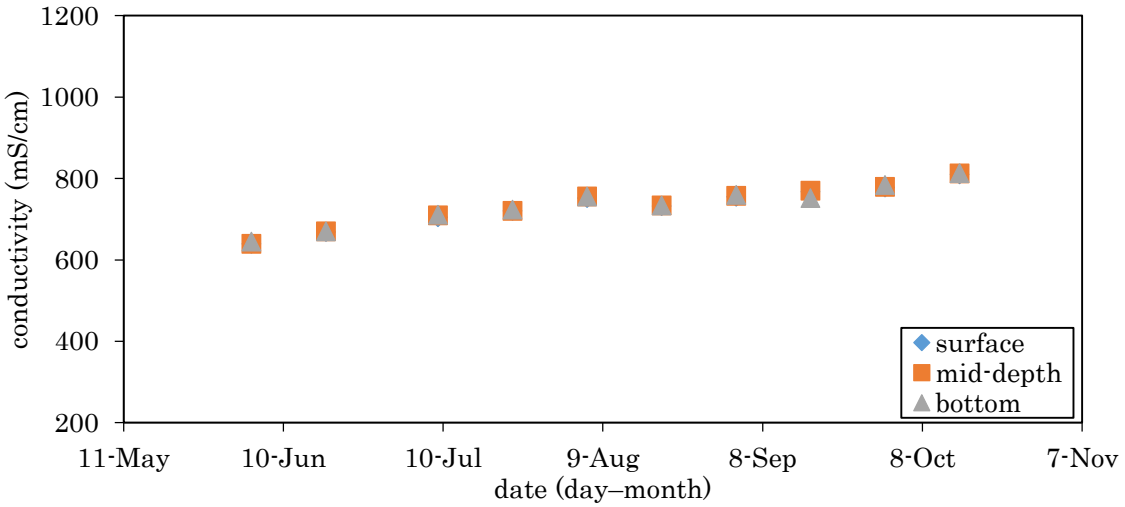

Figure 10. Conductivity at Site A (2010) with aeration in the entire period

Depth-averaged conductivity and STD for all the sites are presented in Table 6. Following observations can be made from analysis of data shown in Table 6: (1) there were very small vertical variations in conductivity at any site as shown by small STD; (2) conductivity continued to increase at all the sites; and (3) conductivity among sites was very

similar. Identical conductivity among sites indicates that the entire reservoir was well mixed in terms of dissolved ions.

Table 6. Depth-averaged conductivity and Standard Deviations (STD), 2010

date (mo/day/yr)	conductivity (average ± STD), mS/cm			
	Site A	Site B	Site C	Site D
6/04/2010	642±3.43	631±12.42	642±2.83	649±10.67
6/18/2010	670±0.79	673±0.50	677±13.52	675±0.82
7/09/2010	709±3.73	710±1.39	703±3.03	709±2.28
7/23/2010	722±3.42	720±1.13	718±1.03	722±9.35
8/06/2010	755±2.39	756±1.38	752±2.28	753±2.70
8/20/2010	733±1.06	733±1.11	733±0.55	732±2.50
9/03/2010	757±2.57	759±0.52	757±1.10	760±2.88
9/17/2010	764±12.87	770±1.00	769±1.00	772±3.44
10/01/2010	781±3.93	780±3.24	780±0.50	783±3.42
10/15/2010	812±1.41	812±0.55		

In 2011, when aeration was in operation, conductivity measurements at Site A, as shown in Figure 11, were similar to those obtained from 2010 study period, showing gradual increase over time and uniform distribution through the depth. However, when the aeration was stopped, conductivity at the surface and at the mid-depth remained approximately constant, but increased at a faster rate in the bottom layer (Figure 11). Vertical profiles of conductivity, as shown in Figure 12, provide additional evidence of this increase of conductivity (dissolve ions) at the bottom. ANOVA confirmed that significant differences of conductivity between sampling depth occurred when aeration was stopped ($p<0.01$, Table E26.). Tukey's test showed no significant differences in conductivity between 0.5 and 4 m depths. However, significant differences in conductivity were found between the surface (0.5m) and at 5.0 m ($p=0.01$) and below (Table E27.). Similar to Site A, higher conductivity in the bottom layer was observed at all sampling sites during non-aerated period. ANOVA results confirmed significant differences of conductivity within the sampling depths at sites B ($p<0.01$), C ($p=0.02$), and D ($p<0.01$) (Tables E28, E30, and E32, respectively).

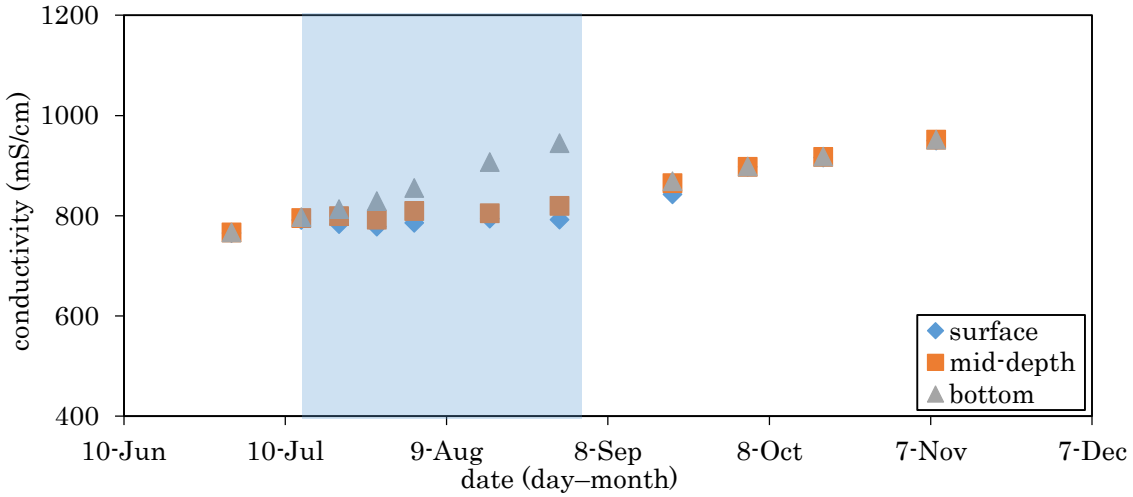

Figure 11. Conductivity at Site A (2011). Shaded area indicates period without aeration.

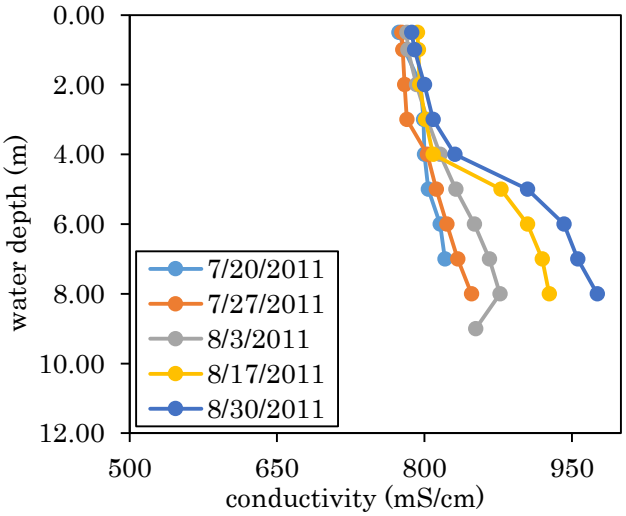

Figure 12. Vertical variation of conductivity at Site A (2011) during non-aerated period

The depth-averaged conductivity data from the sampling sites show that the conductivity was similar at all sites in the reservoir (Table 7). Higher standard deviations at sampling Site A indicate that vertical conductivity differences occurred when the reservoir was not aerated.

Table 7. Depth-averaged conductivity and Standard Deviations (STD), 2011

date (mo/day/yr)	conductivity (average ± STD), mS/cm			
	Site A	Site B	Site C	Site D
6/30/2011	766±0.92	770±0.71	770±4.06	808±89.91
7/13/2011	793±2.98	787±16.08	785±0.84	776±13.97
7/20/2011	**790±16.01**	**790±12.84**	**795±8.11**	**729 ±16.02**
7/27/2011	**784±26.76**	**797±13.77**	**789±8.38**	**790 ± 10.89**
8/03/2011	**795±35.13**	**802±26.40**	**787±14.11**	**798 ±32.37**
8/17/2011	**798±59.21**	**834±51.33**	**796±4.83**	**794 ± 1.64**
8/30/2011	**803±77.74**	**846±53.76**	**805±9.29**	**807±7.29**
9/20/2011	852±12.85	871±0.00	870±0.00	873±1.34
10/04/2011	898±0.44	894±8.42	897±0.84	902±3.83
10/18/2011	917±1.22	915±10.73	927±2.00	920±0.00
11/08/2011	951±1.16	939±27.05	953±0.84	953±3.49

Note: bolded values indicate period without aeration.

Continued increase of conductivity during both sampling seasons and faster increase of bottom layer conductivity during the period when aeration was turned off indicate that dissolved ions, which include dissolved N and P species, were continuously loaded to the reservoir and sediments were the main source. Because the reservoir does not receive continued inflow and is fed by storm runoff, and because no sudden changes of conductivity were observed in both sampling period, it is assumed that loading of dissolved substances, including N and P, from external sources is less important as compared to internal loading from the sediments.

To prove this assumption rainfall data from a nearby weather station were collected and were compared to the variation of average conductivity in the reservoir. Hourly rainfall data were obtained from the North Dakota Agricultural Weather Network (NDAWN) weather station located in Marion, ND (about 20 km from the HMD). Both rainfall data and conductivity data for 2010 and 2011 are presented in Figure 13. Conductivity of runoff usually varies with rainfall intensity and duration, and is likely different from conductivity of the reservoir water. If the impact of runoff on the reservoir water quality were significant, conductivity in the reservoir would show certain degrees of increase or decrease

after each rainfall event. Analyses of data indicate that no changes of conductivity due to precipitation events were occurred (Figure 13). Thus, sediments are identified as the main source of dissolved ions, which caused gradual increase of conductivity in the HMD.

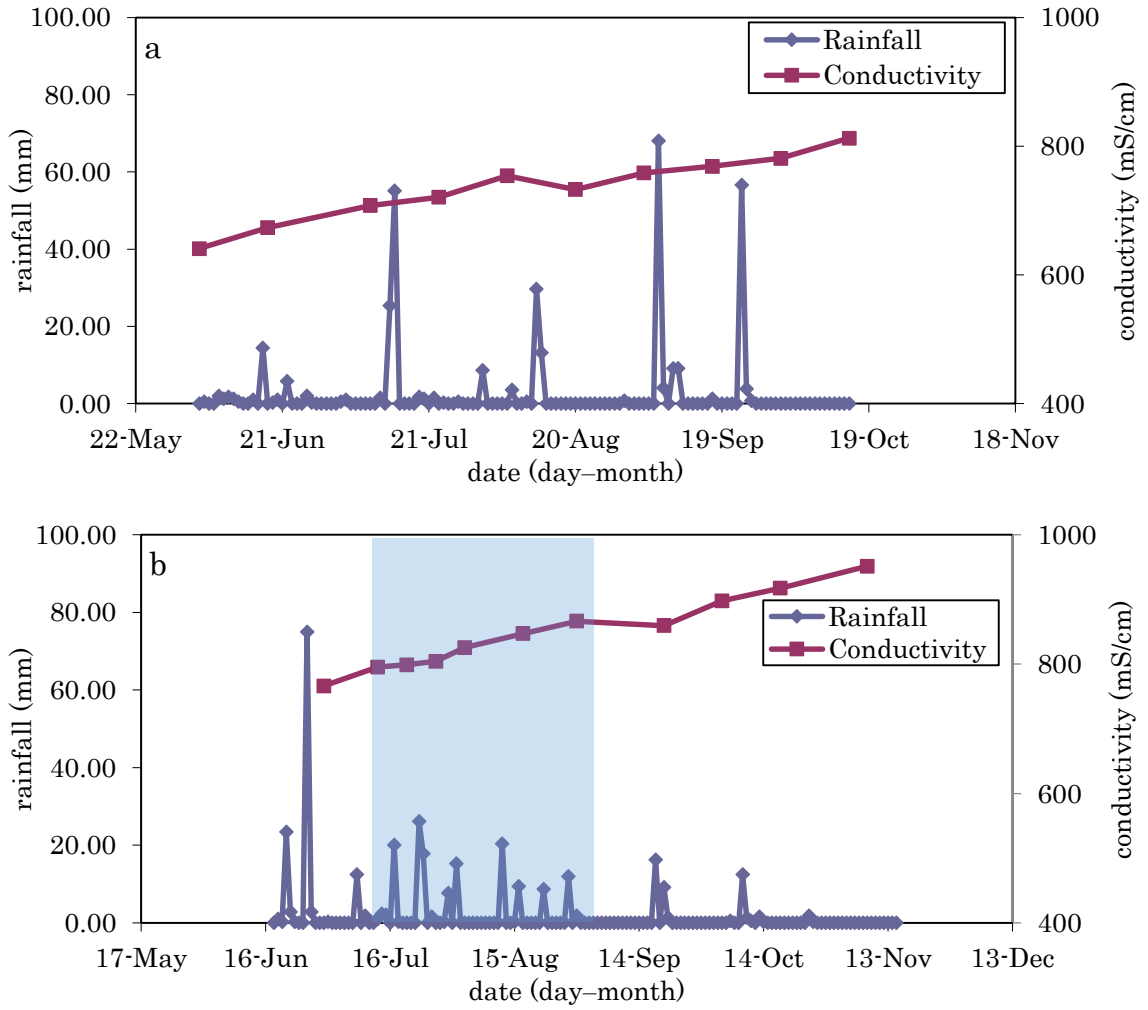

Figure 13. Average conductivity at Site A and rainfall: a) 2010 with aeration during entire period and b) 2011 without aeration in shaded area

4.4.2. Impact of artificial aeration on dissolved oxygen (DO)

The main purpose of operating the aeration system in the HMD was to increase DO concentration in the hypolimnion during summer months by eliminating thermal-stratification. The aeration, as already been discussed in Section 4.4.1.2, was effective in

eliminating thermal stratification. The results of DO measurements at Site A during the aerated 2010 sampling season are shown on Figure 14.

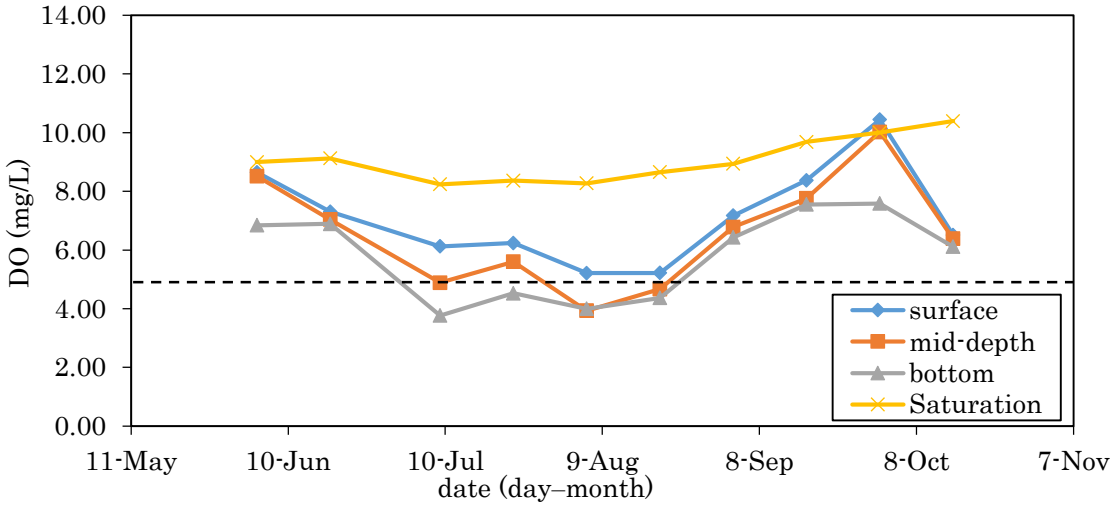

Figure 14. DO concentrations at Site A (2010) with aeration during entire period. Dashed line represents the ND Standard of 5.00 mg/L. DO saturation was calculated based on the surface water temperature

DO concentrations in the deeper part of the impoundment were above 4 mg/L, which suggests that DO concentrations were improved, but was still lower than Water Quality Standard[1] of 5 mg/L (expressed as horizontal dashed line in Figure 14) during the warmest months (July and August). When comparing vertical distribution of DO concentrations showed that DO decreased with the depth. ANOVA results demonstrated that significant differences in DO concentrations with the depth occurred ($p<0.01$, Table E9.). Tukey's test show a no significant differences within the surface layers (between 0.5 and 6.0 m) indicating that the surface layers were still well mixed and aerated. However, significant difference occurred between the surface and bottom (below 7.00 m) layers (Table E10.).

[1] In CHAPTER 33-16-02.1, Standards of quality for water of the state of North Dakota the numeric dissolved oxygen standard of five (5) mg/l as a daily minimum does not apply to the hypolimnion of class III and IV lakes and reservoirs during periods of thermal stratification (reference).

These results suggest that although the mixing generated from aeration and wind were strong enough to eliminate thermal stratification and to create a near well-mixed condition for dissolved contaminants (conductivity), the mixing was not sufficient to eliminate vertical DO variations through the depth of the reservoir. Similar to Site A, the decrease of DO concentrations with the depth were observed at all sites. ANOVA results show significant differences of DO concentrations between surface and bottom layers at sites B ($p=0.03$) and C ($p=0.01$) (Tables E11 and E13, respectively). The observed DO depletion (differences between saturation and observed concentraitons) and decrease of DO through the depth indicate an intensive consumption of DO in the water bottom of the reservoir. No significant differences between the surface and bottom layers were found at Site D ($p=0.37$, Table E15), likely because of better mixing due to wind effect. However, it is important to note that no anoxic condition was observed in the entire reservoir when reservoir was aerated.

Comparison of DO variations (Figure 13) with water temperature variations (Figure 7) over time indicate that DO variations were almost inversely related to temperature variations. However, our results demonstrate that the DO concentrations, even on the surface and especially in the warmest months (July-August), were much lower than calculated DO-saturation points. Hence, the observed decreases of DO concentrations on the surface could not be explained only by temperatures effect. In addition to increased temperatures, the DO is likely depleted by respiration of phytoplankton during the night, decomposition of dissolved organic matter in the water column, and resuspension from sediments.

Depth-averaged DO concentrations at all sampling sites present in Table 8 show that DO concentrations were about 1.5 mg/L lower in July and at the beginning of August at sites A and B than at shallower sites C and D, likely due to depth effect.

Table 8. Depth-averaged DO and Standard Deviations (STD), 2010

date (mo/day/yr)	dissolved oxygen (average ± STD), mg/L			
	Site A	Site B	Site C	Site D
6/4/2010	6.69±2.44	8.25±0.06	7.68±2.45	8.52±1.80
6/18/2010	7.09±0.25	7.41±1.62	7.60±0.25	7.79±0.23
7/9/2010	4.42±1.42	4.55±1.63	6.45±1.38	6.24±1.58
7/23/2010	5.22±1.13	4.90±1.85	6.73±0.90	6.38±1.18
8/6/2010	4.39±0.79	3.81±0.93	5.88±1.31	4.89±0.97
8/20/2010	4.72±0.47	4.06±0.85	4.76±0.78	4.75±0.76
9/3/2010	6.80±0.39	7.20±1.04	7.92±0.38	7.90±0.82
9/17/2010	7.99±1.49	7.56±0.77	8.44±1.02	8.35±0.59
10/1/2010	8.96±2.80	8.73±3.77	10.91±0.40	10.13±1.83
10/15/2010	6.20±0.33	6.17±1.00		

Results of DO measurements at Site A for the 2011 sampling season are shown in Figure 15. After aeration was turned off, DO concentrations in the surface layer (0.5m -2m) were above 6 mg/L, indicating that surface layers remained well oxygenated (Figure 15). After aeration was turned off, DO level in the bottom layer rapidly decreased from 5.75 mg/L to 0.33 mg/L in three weeks and remained near zero until aeration was turned on again. Without aeration, DO concentration dropped rapidly below three meters at Site A (Figure 16). ANOVA results confirmed that a significant difference in DO concentrations between the measured depths at Site A occurred after the aeration was stopped ($p<0.01$, Table E34). Significant differences in DO depth variation were found at Site B ($p<0.01$, Table E36), but no significant differences were found at sites C ($p=0.47$) or D ($p=0.63$)(Tables E38 and E39, respectively.). These results indicate that without mixing from aeration less oxygen was transferred to the deeper part of reservoir. Rapid decrease of DO in the bottom also suggests significant consumption of DO due to decomposition of dissolved organic matter in the water column and on sediment surface. On the other hand,

at shallow parts the wind mixing was efficient enough to increase DO concentrations naturally.

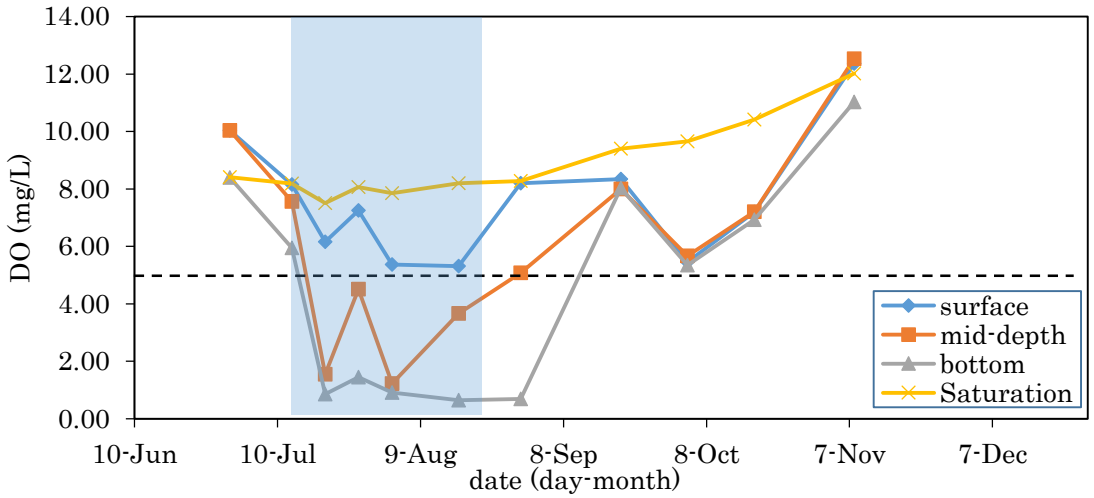

Figure 15. DO concentrations at Site A (2011). Shaded area indicates period without aeration. The dashed line represents the ND Standard of 5.00 mg/L. DO saturation was calculated only for DO concentrations measured at 0.5 m

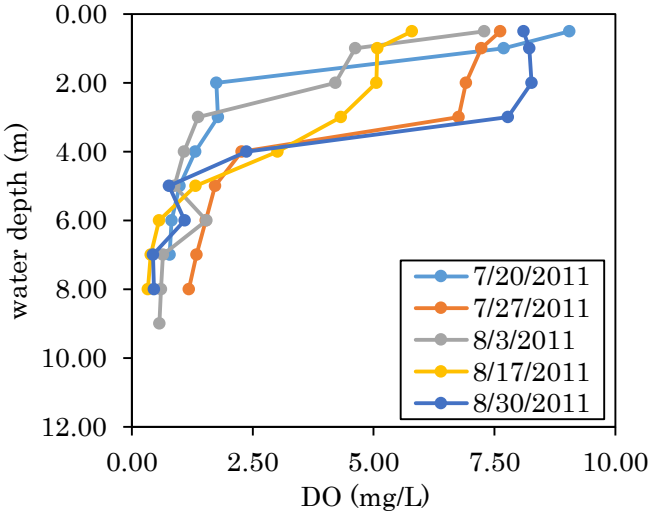

Figure 16. Vertical variation of DO concentrations at Site A (2011) during non-aerated period

The spatial variation of DO among sites was investigated by comparing the depth-averaged DO concentrations among sites (Table 9). Analyses of the data show that depth-averaged DO concentrations during non-aerated period were lower at sites A and B (Table

9). Resuming of aeration resulted in a subsequent recovery of DO concentrations above 6.0 mg/L and the previously differences across the depth were eliminated (Figure 15).

Table 9. Depth-averaged DO and Standard Deviations (STD), 2011

date (mo/day/yr)	dissolved oxygen (average ± STD), mg/L			
	Site A	Site B	Site C	Site D
6/30/2011	8.42±2.95	4.42±0.93	8.91±3.40	7.05±3.48
7/13/2011	6.19±2.23	6.05±0.48	8.52±0.05	6.37±0.50
7/20/2011	**3.02±3.34**	**3.71±4.01**	**8.26±0.36**	**3.58±4.10**
7/27/2011	**4.06±2.93**	**3.94±3.13**	**8.39±0.10**	**5.93±2.78**
8/3/2011	**2.28±2.30**	**4.11±4.22**	**4.22±5.48**	**4.81±3.00**
8/17/2011	**2.87±2.25**	**4.97±2.58**	**6.65±0.19**	**7.85±0.76**
8/30/2011	**4.17±3.73**	**3.73±3.24**	**6.87±1.70**	**6.32±1.79**
9/20/2011	8.13±0.21	8.70±0.21	8.27±0.09	9.01±0.12
10/4/2011	5.43±0.19	5.49±0.19	5.56±5.85	5.85±0.15
10/18/2011	7.08±0.15	6.73±0.26	6.99±0.92	7.44±0.11
11/8/2011	11.90±1.47	12.48±0.25	11.65±0.21	13.15±0.32

Note: bolded values indicate period without aeration.

The rapid decrease in DO concentrations above the sediments can be attributed to combined effect of (1) reestablishment of a weak stratification and limited vertical mixing and oxygen transfer from the surface, and (2) sediment oxygen demand due to high organic contents in the sediments. Solid samples of sediments showed that organic content in the sediments was 13.36% at Site A and 17.4% at Site D in 2011.

4.4.3. Impact of artificial aeration on nutrients release: nitrogen and phosphorus

The samples for nutrient N and P analyses during 2010 were taken only from Site B because data from previous research (Overmoe, 2008) show spatial variations in nutrients concentrations were insignificant due to aeration. In 2011 samples for nutrient analyses were taken from all four sites as described in Table 2. In both years, nutrient samples were at defferent depth to their vertical variations. Since sampling depths for nutrients were not evenly distributed over the water column and varied in each sampling event, a weighted average method was used. The procedure of depth-weighted averaging of concentrations is presented in APPENDIX B.

4.4.3.1. *Impact of artificial aeration on nitrogen concentration in the impoundment*

Total Dissolved Inorganic Nitrogen (TDIN). Nitrate-nitrogen (NO_3^--N), nitrite-nitrogen (NO_2^--N) and ammonia-nitrogen (NH_3-N) are available forms of nitrogen for the growth of phytoplankton, aquatic plants and microorganisms. The sum of measured concentrations of NO_3^--N, NO_2^--N and NH_3-N are added together to present Total Dissolved Inorganic Nitrogen (TDIN). The variations of TDIN at four sampling depths in 2010, when the aeration was in operation, are present in Figure 17. TDIN concentrations at all depths ranged from 0.10–0.22 mg/L and remained relatively constant thorough the sampling period (Figure 17). Since the TDIN remained low and the same all the time, it suggests that N likely is a limited nutrient for phytoplankton growth.

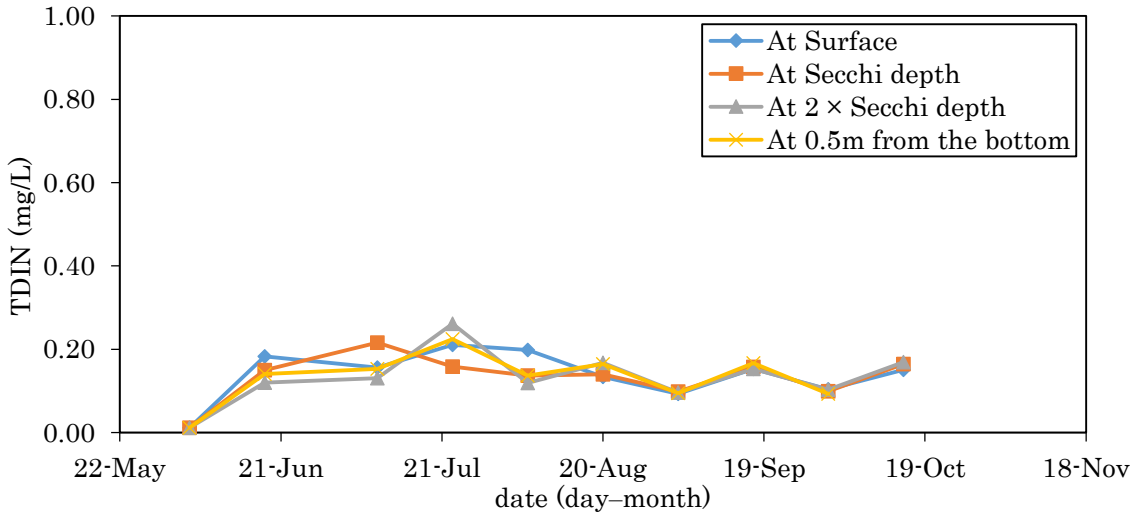

Figure 17. TDIN concentrations at Site B (2010) with aeration during entire period.

Standard deviations of depth-weighted average (DWA) concentrations (Table 10) of TDIN is small indicating that TDIN concentrations at all sampling depths were basically the same in 2010 when aeration worked. ANOVA results confirmed that no significant differences between the depths of TDIN concentrations ($p=0.97$, Table E16). The lack of differences in vertical distribution in TDIN concentrations indicate that the reservoir was well mixed in terms of nitrogen.

Table 10. Depth-weighted average TDIN and Standard Deviations (STD), 2010

date (mo/day/yr)	TDIN (average ± STD), mg/L
	Site B
6/4/2010	0.01±0.00
6/18/2010	0.14±0.02
7/9/2010	0.16±0.03
7/23/2010	0.22±0.05
8/6/2010	0.14±0.03
8/20/2010	0.16±0.01
9/3/2010	0.10±0.01
9/17/2010	0.16±0.00
10/1/2010	0.10±0.00
10/15/2010	0.20±0.04

Most of time NO_3^--N concentrations were above 60% of TDIN, while NH_3-N concentrations were below 30% of TDIN. These results suggest significant nitrification under aerobic condition with aeration.

To make direct comparison with 2010 data, TDIN concentrations measure at Site B are presented in Figure 18. In 2011, stopping of aeration resulted in an increase of TDIN concentrations in the bottom layers at Site B, from 0.07 to 0.94 mg/L, while in the surface layer TDIN concentration decreased from 0.15 to 0.07 mg/L (Figure 18). Significant differences of TDIN concentrations with the depth at Site B was confirmed by ANOVA analyses ($p<0.01$, Table E42). Tukey's test shows that concentrations of TDIN at the Secchi depth and thermocline were not significantly different. However, significant differences occur between layers above and below the thermocline ($p<0.01$, Table E43). At Site A, which was located at the deepest part in the impoundment, the bottom concentrations of TDIN reached even higher values of 1.17 mg/L (Table A35). Similarly, significant differences between the depths were found at Site A (Table E40) as well. The accumulation of TDIN on the bottom of the reservoir indicates that the sediment is the major source of nitrogen.

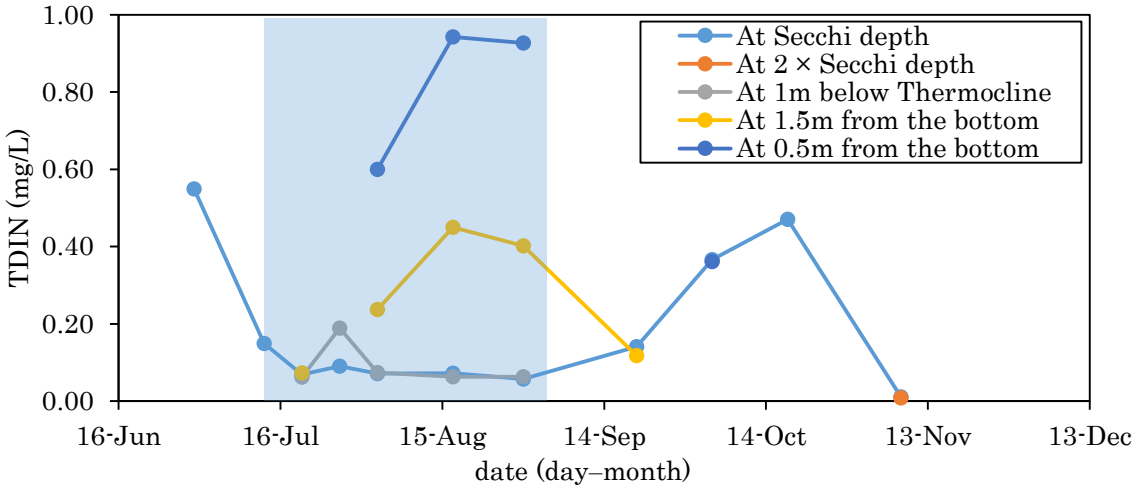

Figure 18. TDIN concentrations at Site B (2011). Shaded area indicates period without aeration.

Depth-weighted average (DWA) concentrations and STD of TDIN for Sites A and B, as shown in Table 11, indicate that concentrations of TDIN gradually increased. Samples for TDIN analysis from Sites C and D were only taken from Secchi depth. Results show that concentrations remained relatively constant over non-aertaed period and were the same as concentrations at Sechhi depth at Sites A and B (data are available in APPENDIX A). Increases of concentrations at Sites A and B indicates TDIN accumulated at the bottom of the reservoir as a result of reduced mixing and accumulation of TDIN in the bottom layer.

Table 11. Depth-weighted average TDIN and Standard Deviations (STD), 2011

date (mo/day/yr)	TDIN (Average ± STD), mg/L			
	Site A	Site B	Site C	Site D
6/30/2011	0.43	0.55	0.38	0.3
7/13/2011	0.17	0.15	0.12	0.13
7/20/2011	**0.15±0.09**	**0.07±0.01**	**0.06**	**0.05**
7/27/2011	**0.23±0.11**	**0.14±0.05**	**0.09**	**0.11**
8/3/2011	**0.30±0.26**	**0.20±0.22**	**0.08**	**0.07**
8/17/2011	**0.29±0.26**	**0.29±0.34**	**0.07**	**0.07**
8/30/2011	**0.45±0.53**	**0.28±0.34**	**0.05**	**0.07**
9/20/2011	0.13±0.03	0.09±0.08	0.13	0.08
10/4/2011	0.38±0.02	0.36±0.00	0.33	0.35
10/18/2011	0.19	0.47	0.46	0.48
11/8/2011	0.12±0.00	0.01±0.01	0.12	0.11

Note: bolded values indicate period without aeration.

Under non-aerated conditions, ammonia-nitrate was 68-93% of TDIN on the bottom at Site B, which makes NH_3-N a major nitrogen species. Increase of bottom NH_3-N concentrations from 0.02 to 0.86 mg/L at Site B and from 0.18 to 1.08 mg/L at Site A (Tables A45 and A32, respectively.) during that period is associated with the low DO concentrations, by which nitrification is not favorable. The rapid increase of NH_3-N at the bottom of the reservoir also suggests intensive biological reactions that results in NH_3-N release.

To investigate the effect of aeration on TDIN availability for phytoplankton, TDIN concentrations at Secchi depth at site B were compared between non-aerated period in 2011 and similar period in 2010 with aeration (Figure 19). Results show that TDIN concentrations in 2010 were 1 to 2 times higher than concentrations in 2011. Wilcoxon Mann-Whitney's test confirmed a significant difference between both periods (p=0.02, Table E107.). Thus higher TDIN concentrations, due to aeration, indicate that the aeration contributed to higher nitrogen availability on the surface in the reservoir.

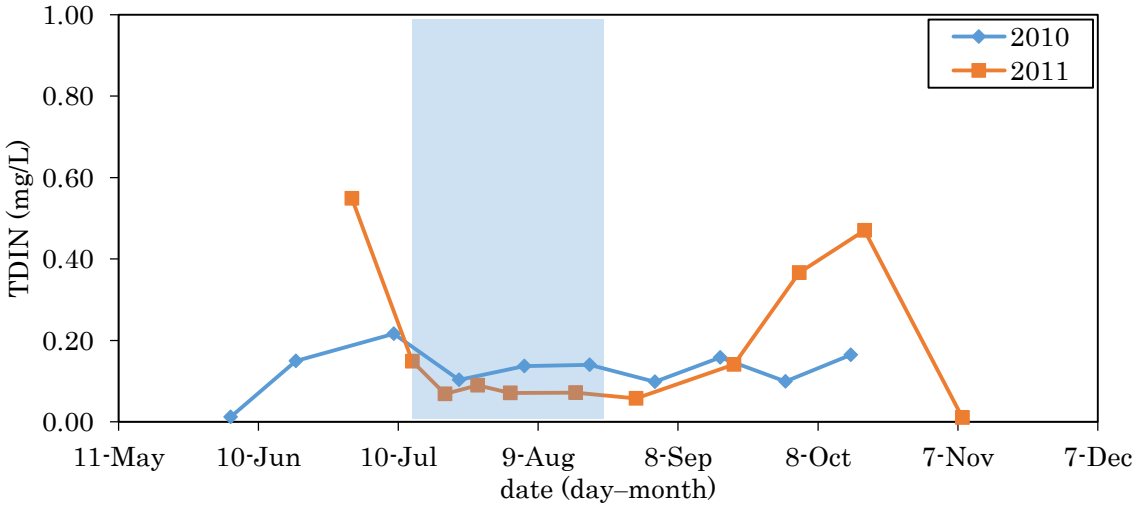

Figure 19. Depth-weighted average TDIN concentrations on Secchi depth at Site B: 2010 with aeration during entire period and 2011 without artificial aeration in shaded area.

Total Nitrogen (TN). Total nitrogen is an important parameter in estimating nitrogen loading in lakes and reservoirs. As shown in Figure 20 during 2010, TN concentrations were similar at all depths. The calculated depth-weighted average TN concentrations ranged between 1.25-2.75 mg/L during the entire sampling season (Table 12). No significant differences were found in vertical distribution of TN concentrations, which was confirmed by ANOVA analysis (p=0.68, Table E17). These result suggest that inorganic (TDIN) and organic (phytoplankton, detritus) forms of nitrogen were nearly evenly dispersed through the water column due to aeration.

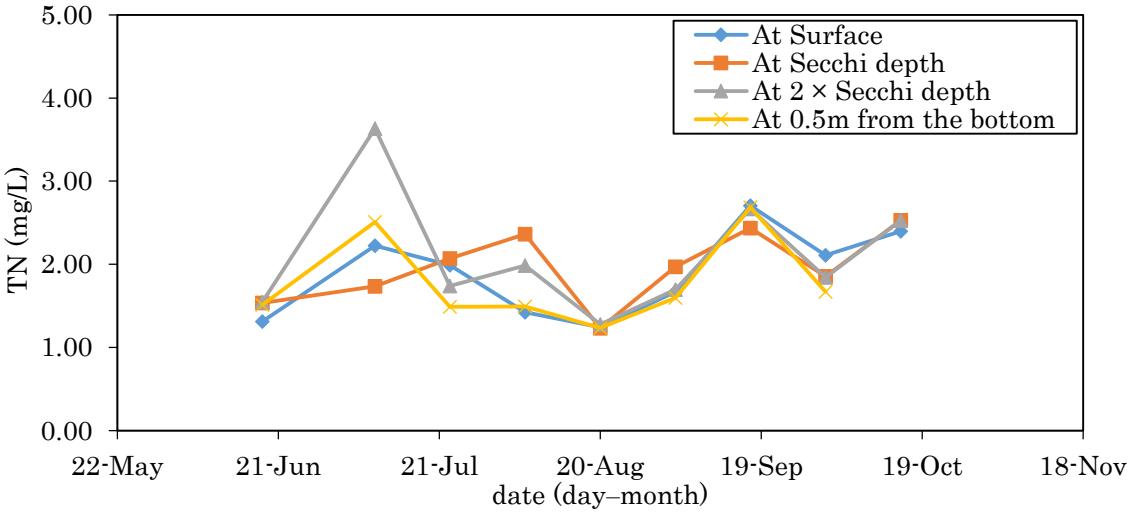

Figure 20. TN concentrations at Site B (2010) with aeration in the entire period

Table 12. Depth-weighted average TN and Standard Deviations (STD), 2010

date (mo/day/yr)	TN (Average ± STD), mg/L Site A
6/4/2010	
6/18/2010	1.50±0.08
7/9/2010	2.75±0.73
7/23/2010	1.70±0.19
8/6/2010	1.74±0.34
8/20/2010	1.25±0.02
9/3/2010	1.71±0.13
9/17/2010	2.64±0.10
10/1/2010	1.83±0.12
10/15/2010	2.51±0.05

In comparison with organic nitrogen data (Figure 21), variations of TNconcentrations followed closely to the variation of TN concentrations. These results suggest that large proportion of TN consist of organic nitrogen containing phytoplankton, detritus, and resuspended organic matter. Since TDIN concentrations were evenly distributed over the water column (Section 4.4.3.1), the slight increase of TN at the surface and at the Secchi depth in summer months was probably due to higher phytoplankton growth at these depths.

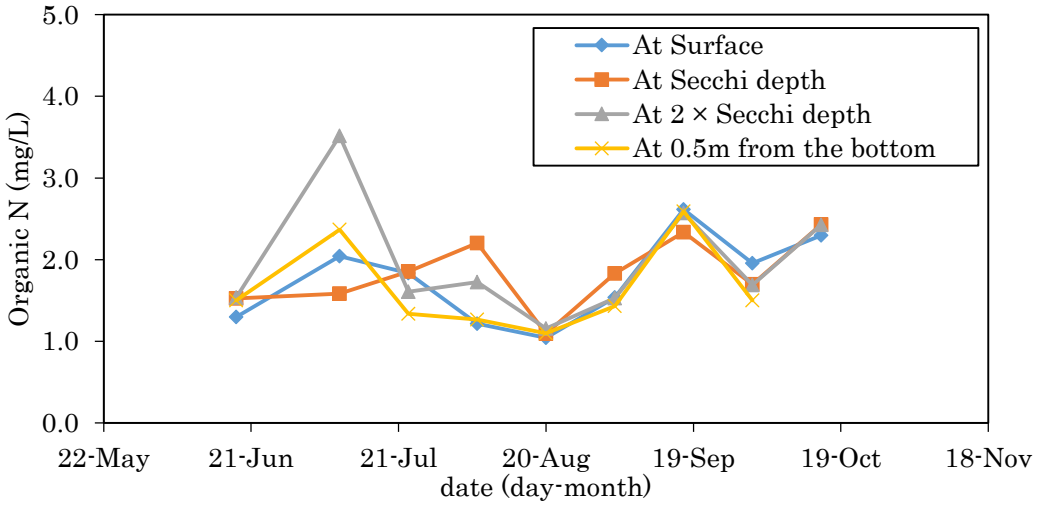

Figure 21. Organic-N concentrations at Site B (2010) with aeration in the entire period

During the period without aeration in 2011, TN concentrations increased at all depths at Site B (Figure 22). ANOVA confirmed no significant depth variations at Site B ($p=0.62$), as well as at Site A ($p=0.62$) (Tables E45 and E44, respectively). Similar to 2010, organic nitrogen comprised a majority of TN concentration (Figure 23). Since the mixing of aeration did not occur, higher concentrations on the surface layers were probably due to phytoplankton growth on the surface, while on the bottom most of the organic nitrogen consisted of detritus. Depth-weighted averaged TN concentrations for all sites, shown in Table 13, were similar and followed the same variation with time at all sampling sites.

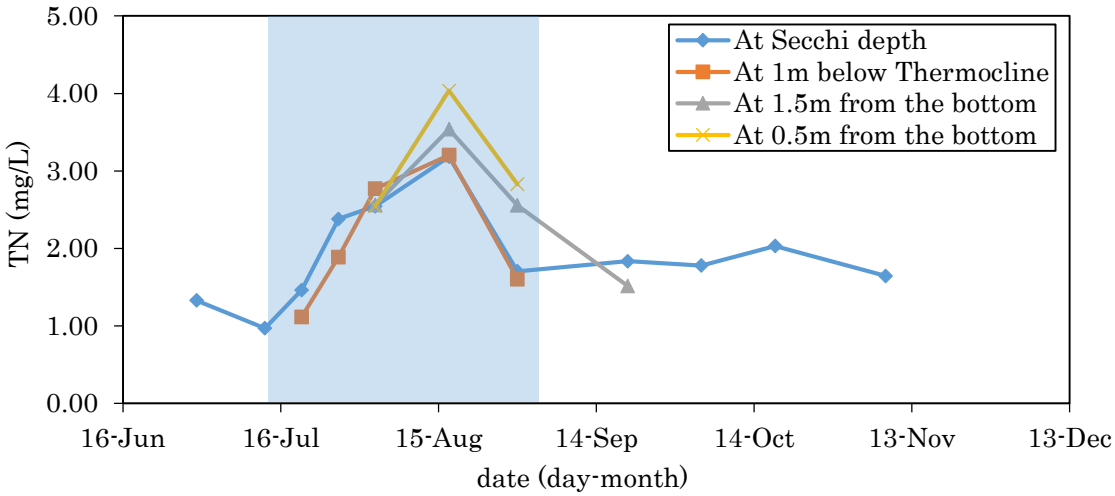

Figure 22. TN concentrations at Site B (2011). Shaded area indicates period without aeration.

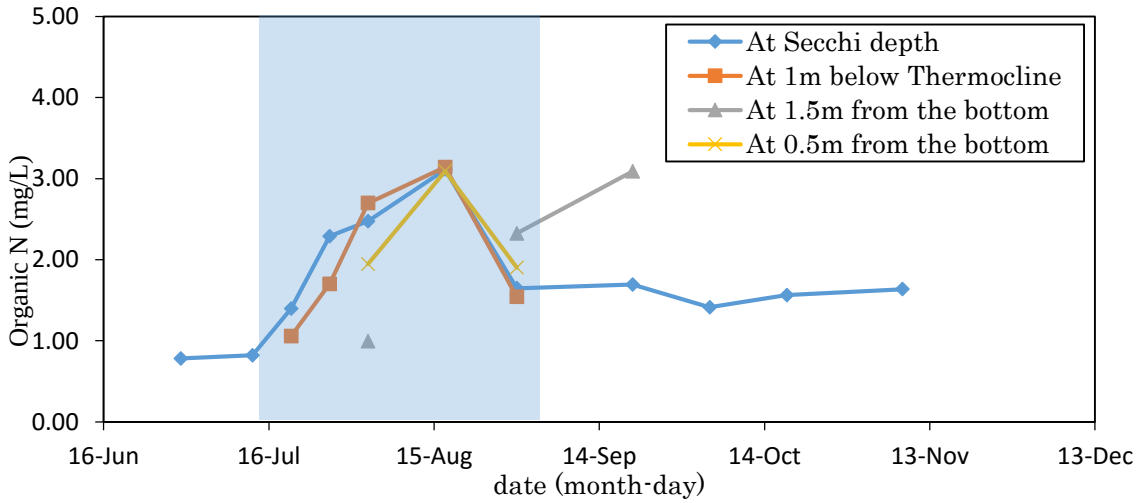

Figure 23. Organic-N concentrations at Site B (2011). Shaded area indicates period without aeration.

Table 13. Depth-weighted average TN and Standard Deviations (STD), 2011

date mo/day/yr	TN (Average ± STD), mg/l			
	Site A	Site B	Site C	Site D
06/30/2011	1.27	1.34	1.26	1.24
07/13/2011	1.07	0.97	0.93	0.97
07/20/2011	**1.27±0.25**	**1.23±0.17**	**1.34**	**1.43**
07/27/2011	**1.77±0.21**	**2.12±1.27**	**2.22**	**3.02**
08/03/2011	**3.19±0.59**	**2.62±0.11**	**2.77**	**3.18**
08/17/2011	**3.55±0.37**	**3.41±0.32**	**2.85**	**3.29**
08/30/2011	**2.23±1.12**	**2.06±0.54**	**1.70**	**1.78**
09/20/2011	1.51±0.19	1.24±1.00	1.62	1.92
10/04/2011	1.75±0.09	1.72±0.04	2.07	1.82
10/18/2011	0.97	2.04	2.03	1.96
11/08/2011	2.02±0.06	1.56±0.05	1.68	1.58

Note: bolded values indicate period without aeration

4.4.3.2. *Impact of artificial aeration on nitrogen release of phosphorus*

Soluble Reactive Phosphorus (SRP).

In aquatic environments, SRP is the biologically available form for phytoplankton growth. Variations in SRP concentrations from 2010 are present in Figure 24. There is very little vertical variation of SRP. Small standard deviations of DWA SRP concentrations indicate that concentrations were similar at all depths (Table 14). ANOVA analysis confirmed no significant differences in SRP concentrations with the depth ($p=0.93$, Table E18.). Gradual increase of SRP concentrations from 0.07 mg/L to 0.18 mg/L was observed from June to August followed by a steady decrease to 0.06 mg/L by the end of sampling period in October.

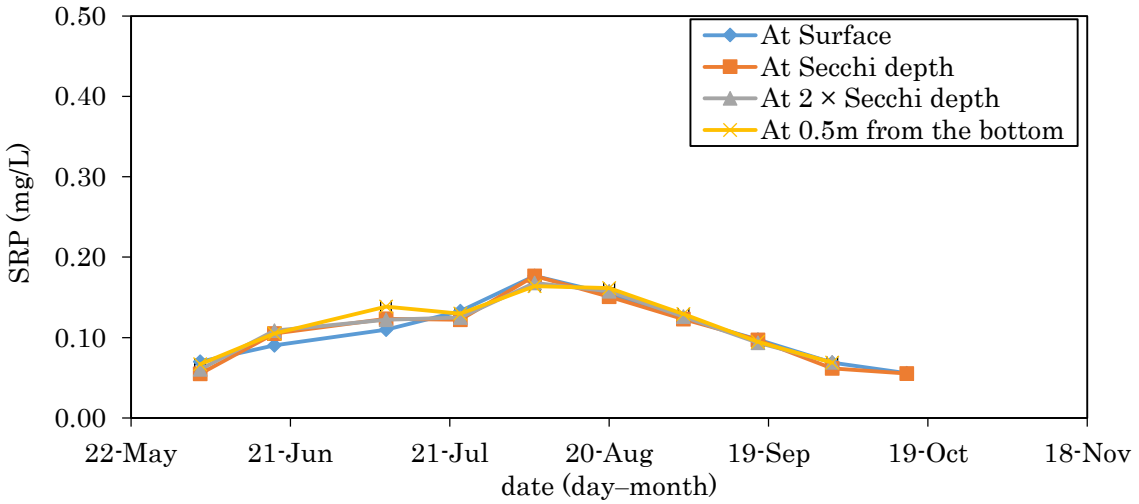

Figure 24. SRP concentrations at Site B (2010) with aeration in the entire period.

Table 14. Depth-weighted average SRP and Standard Deviations (STD), 2010

date (mo/day/yr)	SRP (average ± STD), mg/L
	Site B
6/4/2010	0.06±0.01
6/18/2010	0.10±0.01
7/9/2010	0.13±0.01
7/23/2010	0.13±0.00
8/6/2010	0.17±0.00
8/20/2010	0.16±0.00
9/3/2010	0.13±0.00
9/17/2010	0.10±0.00
10/1/2010	0.07±0.00
10/15/2010	0.07±0.01

The observed linear increases of SRP concentrations indicate continuous addition and accumulation of P to the water body. This contined increase of P also indicates that P was not consumed by phytoplankton as fast as it been added to the reservoir and it was in an excess for phytoplankton growth. Comparison between variations of SRP concentrations (Figure 24) and temperature variations (Figure 7) over time indicate that SRP variations follow temperature variation. These finding are important because some authors linked increase of P release to temperature. Temperature may increase increase phosphate solubility (Coffman & Kildsig, 1996; Wu et al., 2011). On the other hand, higher

temperatures increase many biologically mediated processes that in turn result in more P-release (Jensen & Andersen, 1992; Gächter & Meyer, 1993; Liu et al., 2009; Wu et al., 2011)

In 2011, when aeration was turned off, SRP concentrations built up from 0.31 to 0.41 mg/L on the bottom layer at Site B, while on the surface it decreased and remained relatively low for the rest of non-aerated period (Figure 25). ANOVA results confirm that significant differences among the sampling depths occur when aeration was stopped ($p<0.05$, Table E48.). Tukey's test shows that concentrations of SRP at the 0.5m from the bottom were significantly higher than concentrations at the Secchi depth ($p<0.05$) and at the thermocline ($p<0.05$). Significant differences between the sampling depths were observed also at Site A ($p<0.01$, Table E46.). Significantly, higher concentrations of SRP on the bottom layers in comparison with surface layers indicate that the P is released from the sediments.

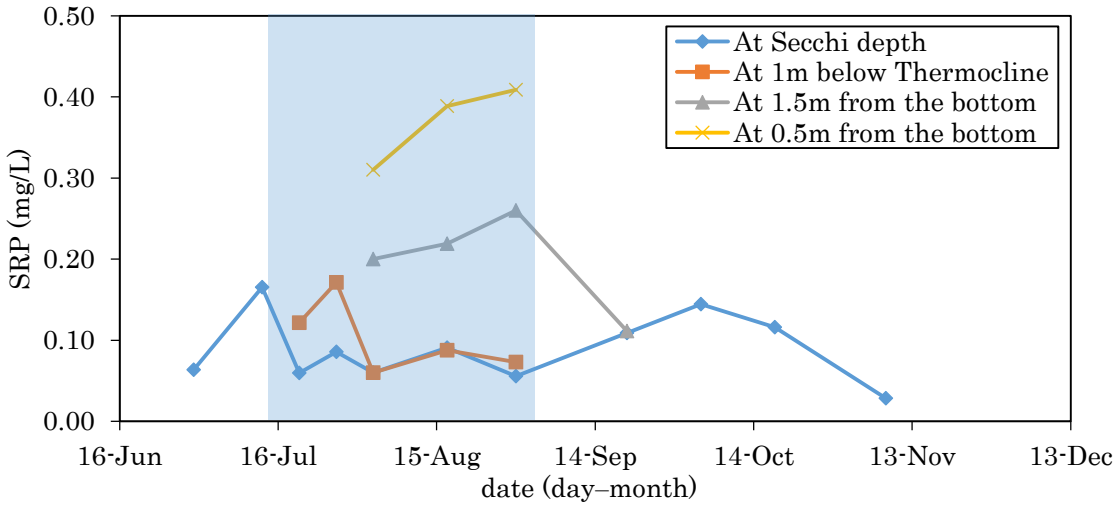

Figure 25. SRP concentrations at Site B (2011). Shaded area indicates period without aeration.

Comparison of depth-weighted average SRP concentrations among the sampling sites show that DWA concentrations at Sites A and B increased gradualy, indicating that the P was continuously addedto the water column under anaerobic condition. Relatively

higher were concentrations atthe deepest Site A (Table 15). SRP concentrations at Sites C and D, which were measured only at Secchi depth, remined relatively constant and were the same as concentrations at Secchi depth at Sites A and B over the non-aerated period (data are available in APPENDIX A).

Table 15. Depth-weighted average SRP and Standard Deviations (STD), 2011

date (mo/day/yr)	SRP (average ± STD), mg/L			
	Site A	Site B	Site C	Site D
6/30/2011	0.06	0.43	0.06	0.05
7/13/2011	0.17	0.17	0.16	0.16
720/2011	**0.13±0.06**	**0.11±0.07**	**0.07**	**0.06**
7/27/2011	**0.20±0.11**	**0.13±0.11**	**0.08**	**0.09**
8/3/2011	**0.24±0.18**	**0.13±0.11**	**0.06**	**0.06**
8/17/2011	**0.18±0.11**	**0.16±0.13**	**0.09**	**0.08**
8/30/2011	**0.21±0.20**	**0.16±0.15**	**0.06**	**0.07**
9/20/2011	0.10±0.01	0.07±0.07	0.11	0.11
10/4/2011	0.15±0.00	0.14±0.00	0.15	0.14
10/18/2011	0.12	0.12	0.12	0.12
11/8/2011	0.03±0.08	0.01±0.01	0.03	0.03

Note: bolded values indicate period without aeration

According to the classical explanation P flux at the sediment-water interface is controlled primarily by redox potential which determines release of iorn bound P or formation of FeOOH-PO_4 precipitates(Einsele, 1936; Mortimer, 1941, 1942). From DO data it, is evident that an anoxic condition was established after the aeration was turned off (Figure 15 in section 4.4.2). Therefore, release of phosphorus from anoxic sediments during thermal stratification in the HMD follows expectations. The differences in SRP concentrations between the sampling sites indicate faster accumulation on of P the bottom of the deepest part in the reservoir.

Similarly, to the TDIN, the comparison of SRP concentrations at the Secchi depth between 2010 and 2011 at Site B (Figure 26) show that concentrations were 1 to 2.5 times higher when lake was aerated. WMW test show significant difference between SRP

concentrations during aerated and non-aerated period (p=0.02, Table E108.). Thereby, aeration made P more available for phytoplankton on the surface in the HMD

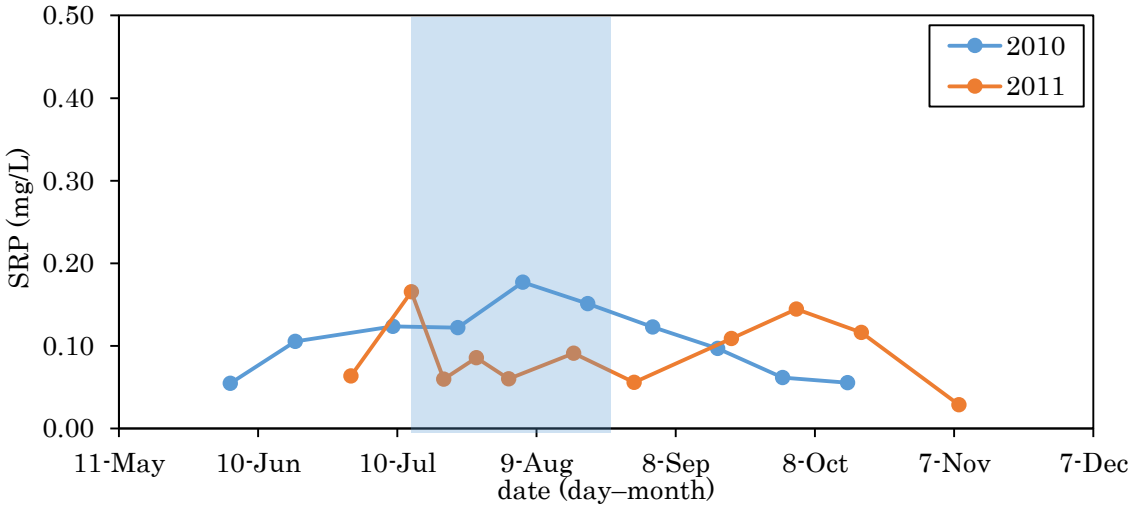

Figure 26. SRP concentrations on Secchi depth at Site B: 2010 with aeration during entire period and 2011 without artificial aeration in shaded area.

Total phosphorus (TP). In 2010, when the reservoir was aerated, TP concentrations increased from spring to summer at all depths at Site B (Figure 27). The depth-weighted average TP concentrations gradually increased from 0.13 mg/L to 0.24 mg/L, and after August, TP concentrations gradually decreased (Table 16). Small standard deviations of DWA TP concentrations (Table 15) indicate that TP was similar at all depths during the artificially mixed entire season. ANOVA results confirmed that no significant differences between depths when lake was aerated (p=0.99, Table E19), indicating that the TP was equally distributed thorough the water column.

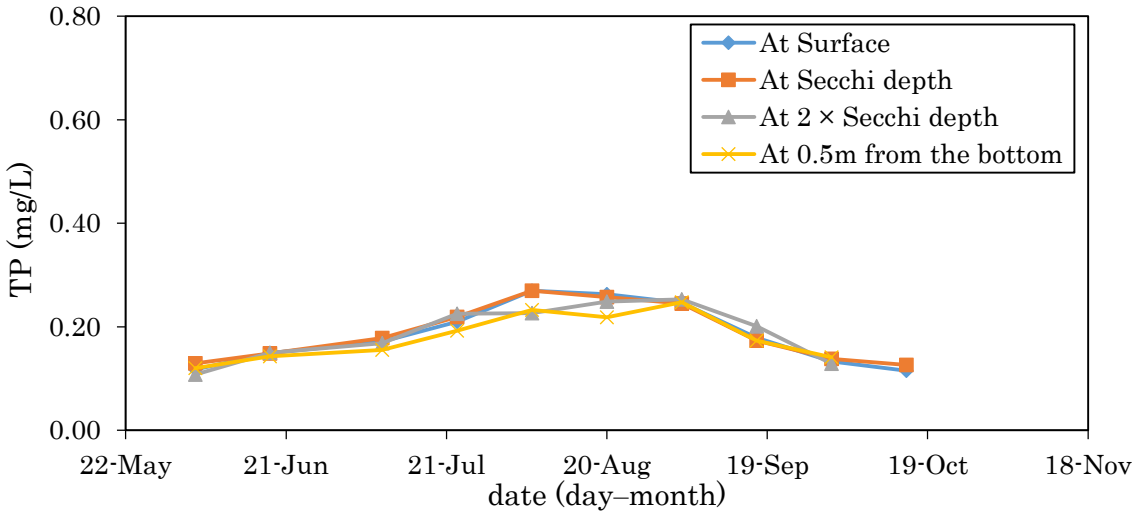

Figure 27. TP concentrations at Site B (2010) with aeration during entire period

Table 16. Depth-weighted average TP and Standard Deviations (STD), 2010

date (mo/day/yr)	TP (average ± STD), mg/L
	Site B
6/4/2010	0.12±0.01
6/18/2010	0.15±0.00
7/9/2010	0.16±0.01
7/23/2010	0.21±0.01
8/6/2010	0.24±0.02
8/20/2010	0.24±0.02
9/3/2010	0.25±0.00
9/17/2010	0.18±0.01
10/10/2010	0.13±0.01
10/15/2010	0.12±0.01

In 2011, after stopping aeration, TP concentrations at the surface of Site B decreased from 24 mg/L (July) to 0.18 mg/L (August), while at the bottom concentrations rapidly increased from 0.24 mg/L to 0.55 mg/L (Figure. 28). At Site A, TP concentrations at the bottom increased more rapidly from 0.24 to 0.70 mg/L (Table A37).

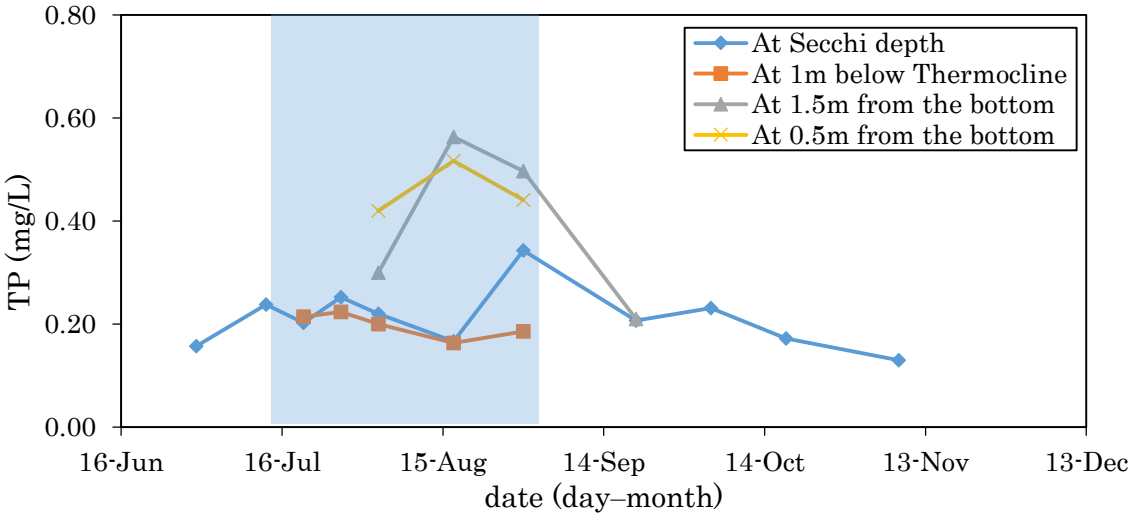

Figure 28. TP concentrations at site B (2011). Shaded area indicates the period without aeration.

TP accumulation in the deeper part in the impoundment indicates internal origin of the P in the impoundment. Data of TP DWA concentrations at Sites A and B were relatively higher than TP concentrations at Sites C and D (Table 17). Table 17 also show, that TP concentrations followed similar distribution over time at all sites.

Table 17. Depth-weighted average TP and Standard Deviations (STD), 2011

date (mo/day/yr)	TP (Average ± STD), mg/L			
	Site A	Site B	Site C	Site D
6/30/2011	0.15	0.16	0.14	0.13
7/13/2011	0.24	0.24	0.21	0.23
7/20/2011	**0.22±0.01**	**0.21±0.01**	**0.21**	**0.20**
7/27/2011	**0.30±0.09**	**0.24±0.02**	**0.22**	**0.21**
8/3/2011	**0.35±0.17**	**0.26±0.09**	**0.18**	**0.20**
8/17/2011	**0.27±0.12**	**0.31±0.20**	**0.34**	**0.25**
8/30/2011	**0.40±0.22**	**0.35±0.13**	**0.35**	**0.40**
9/20/2011	0.22±0.03	0.21±0.00	0.24	0.26
10/4/2011	0.22±0.03	0.27±0.02	0.23	0.22
10/18/2011	0.18	0.05	0.18	0.19
11/8/2011	0.13±0.01	0.14±0.01	0.13	0.12

Note: bolded values indicate period without aeration.

4.4.4. Nutrient load analysis

To determine the effect of artifitial aeration on internal nutrient release rate, TP flux from sediments was estimated using the data from 2010 (June 18th-August 20th) and

2011 (non-aerated, July 20th-August 30th). In 2010, since the aeration eliminated spatial variation in concentrations, the TP concentrations were measured only at Site B. For 2011, the TP data, from all sites (A, B, C and D) were used for calculations. Changes of TP concentration in these two study periods are presented in Figure 29. Linear regression was used to determine the rate of TP changes.

The TP flux was calculated using Equation 4.1:

$$J_P = \frac{\Delta C_P}{\Delta t} \times \bar{H} \qquad \text{(Equation 4.1)}$$

where: J_P – flux of TP (mg/m²·day)
$\mathbf{C_P}$ – depth-weighted averaged TP concentrations in water column (mg/L)
t – time in (days)
$\bar{H}$ – mean depth (m)

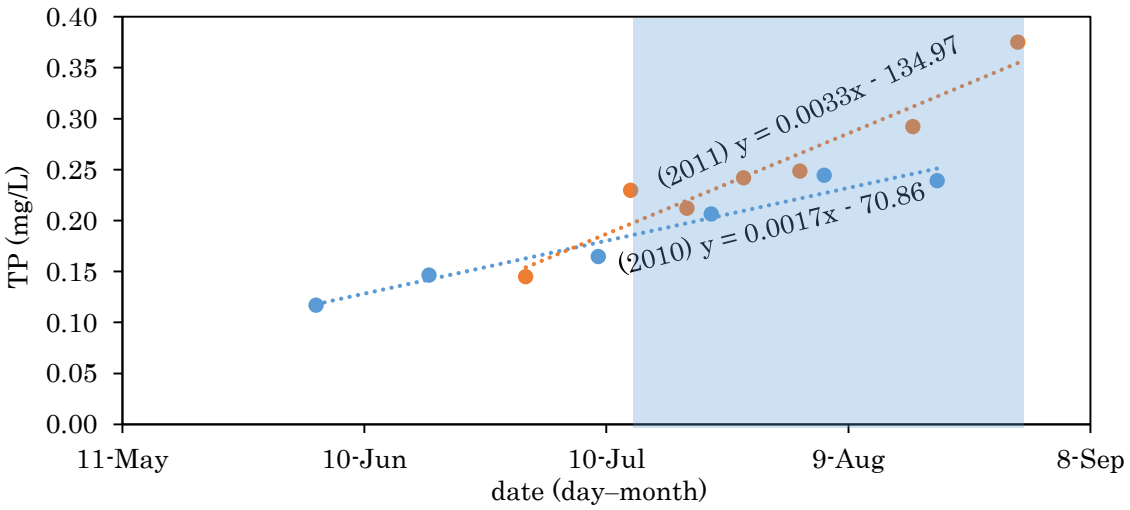

Figure 29. TP concentration changes: 2010 with aeration during entire period and 2011 without artificial aeration in shaded area.

Depth-weighted average TP concentrations show that the TP release rate in 2010 was about half of the release rate in 2011 for the same time of the year, suggesting that aeration reduced P release from sediments (Figure 29). Using Equation 1, average P-flux in 2010 was determined to be 0.0068 mg/m²·day, while in 2011 it was 0.0142 mg/m²·day. These results show that the TP loading was reduced by 47%, due to aertaion.

4.4.5. Effect of artificial aeration on Chlorophyll-*a* (Chl-*a*)

Variation of Chl-*a* concentration in 2010, when the reservoir was aerated, is presented in Figure 30. The Chl-*a* concentrations at the surface at Site A increased from 14.43 µg/L in June to 43.84 µg/L by the end of July, 2010. After September, the Chl-*a* concentrations decreased as a general trend toward fall months (Figure 30). Similar variation in Chl-*a* concentrations were observed at all four sampling depths at Site A during the entire period.

Analysis of vertical distribution of Chl-*a* at Site A shows in the beginning of 2010, the Chl-*a* concentrations in deeper layers were similar to the Chl-*a* concentrations at the surface. These results suggest that mixing due to aeration dispersed phytoplankton into deeper layers of the reservoir. Higher Chl-*a* concentrations for about two weeks in the mid-summer at Secchi depth were observed at Site A, which is located close to diffusers and in the deepest part in the impoundment (Figure 30). Althought, observed differensces, Chl-*a* concentrations on the bottom were relatively higher and increased in summer monts indicating that aeration was still able to disperce phytoplankton cells deeper in the reservoir.

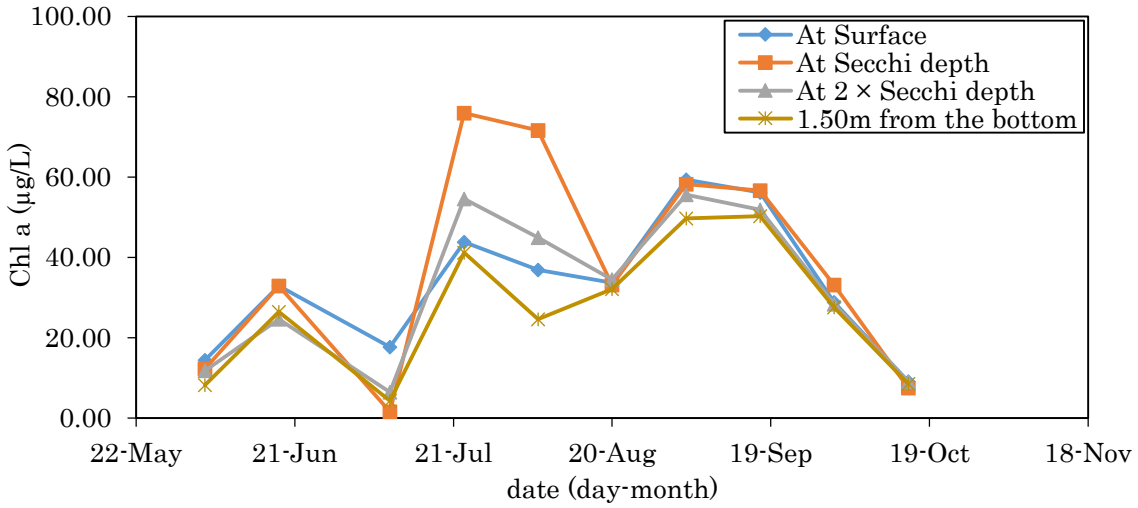

Figure 30. Chl-*a* concentrations at Site A (2010) with aeration in the entire period.

Higher Chl-*a* concentrations were also observed at the surface and the Secchi depth at Site B (Table A10), but no vertical Chl-*a* differences were observed at Sites C and D (Tables 21 and 26, respectively.). Similarly, relatively higher Chl-*a* concentrations below the surface has been observed in many deep lakes. Such accumulation of phytoplankton has been related to adaptation of phytoplankton to avoid higher light intensity on the surface (Camacho et al., 2003). Hence occurrence of such accumulation, of Chl-*a* below the surface suggest that the artificial mixing in the HMD is gentle and not strong.

For the whole period ANOVA results show no significant differences in Chl-*a* concentrations between depths at Site A ($p=0.68$, Table E54.). Similarly, no differences between sampling depths were found at Sites B ($p=0.78$), C ($p=0.61$), and D ($p=0.47$) (Tables E55, E56, and E57, respectively). Since the Chl-*a* fluctuate largely over time, in this case ANOVA could not be reliably used to assess the Chl-*a* distribution over time.

Among the sites, depth-weighted averaged Chl-*a* show that the Chl-*a* variation were similar at all sites (Table 18). Relatively higher were concentrations at shallower Sites C and D in the end of July in comparison with deeper sites A and B.

Table 18. Depth-weighted average Chl-*a* and Standard Deviations (STD), 2010

date (mo/day/yr)	Chl-*a* (average ± STD), µg/L			
	Site A	Site B	Site C	Site D
6/4/2010	11.34 ± 2.39	12.99 ± 0.50	14.32 ± 1.64	16.56±2.77
6/18/2010	27.59 ± 3.54	30.09 ± 1.21	22.73 ± 1.64	19.05±16.41
7/9/2010	6.33 ± 5.32	7.67 ± 1.46	19.59 ± 13.27	13.05±5.08
7/23/2010	50.21 ±12.39	49.48 ± 19.60	97.96 ± 0.27	158.42±0.46
8/6/2010	41.77 ±18.29	51.37 ± 21.42	49.43 ± 14.33	52.58±18.11
8/20/2010	33.18 ± 1.08	40.08 ± 15.85	61.16 ± 21.70	89.23±30.61
9/3/2010	54.90 ± 4.40	72.26 ± 2.62	56.70 ± 4.90	76.56±7.56
9/17/2010	52.80 ± 2.96	51.86 ± 16.97	58.16 ± 9.11	57.16±9.51
10/10/2010	29.29 ± 2.37	26.71 ± 11.43	34.17 ± 14.93	26.07±5.66
10/15/2010	8.55 ± 2.65	2.65±3.36		

Similarly to 2010, in the beginning of 2011, when the reservoir was artificially aerated, the surface Chl-*a* at Site A increased rapidly from 2.67 to 32.08 µg/L (Figure 31). A

week after aeration was stopped and stratification was developed, Chl-*a* rapidly increased on the surface layers from 32 µg/L to 79 µg/L, but was lower in deeper part of the water column, indicating that phytoplankton accumulated on the surface. ANOVA results confirmed that a significant differences of Chl-*a* concentrations among the sampling depths occur after the aeration was stopped ($p<0.01$, Table E58). The Tukey's test show that Chl-*a* concentrations were significantly different at the surface and at the Secchi depth than at the thermocline, 1.5m from the bottom and 0.5m from the bottom. No significant difference was found between the surface and Secchi depth, which confirms that phytoplankton accumulated in the surface layers (Table E59). Similar significant differences with the depth were found at Site B ($p=0.03$) (Table E60). Based on p-values for Sites C ($p=0.06$) and D ($p=0.08$) (Tables E62 and E63, respectively.) we cannot conclude that there were a significant across sampling depths with the same confidence.

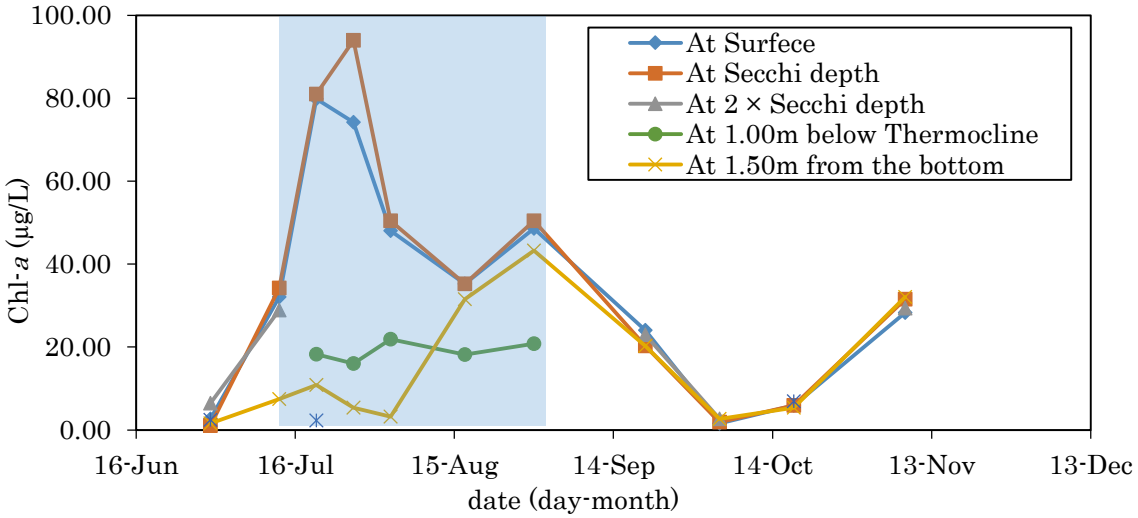

Figure 31. Chl-*a* concentrations at Site A (2011). Shaded area indicate period without aeration.

It is important to note, that although nutrient concentrations on the surface decreased, stopping of aeration did not affected phytoplankton growth immediately. Increase of surface Chl-*a* concentrations indicates that the phytoplankton population

continue to grow for the first two weeks after stopping of the mixing (Table 31). The depth-weighted averaged Chl-*a* concentrations (Table 19) also indicate that the Chl-*a* concentrations have similar distribution at all sites. Two weeks after stopping of aeration the Chl-*a* rapidly decreased indicating a collapse of the phytoplankton population.

Table 19. Depth-weighted average Chl-*a* and Standard Deviations (STD), 2011

date (mo/day/yr)	Chl-*a* (average ± STD), µg/L			
	Site A	Site B	Site C	Site D
6/30/2011	3.15±2.30	7.19±5.16	15.07±2.61	12.70±1.78
7/13/2011	21.30±12.29	13.31±6.74	25.55±10.61	9.46±12.39
7/20/2011	**31.58±33.73**	**28.22±22.73**	**19.59±17.15**	**32.87±26.05**
7/27/2011	**34.73±39.13**	**40.89±37.75**	**40.48±24.19**	**54.89±2.79**
8/3/2011	**20.58±15.50**	**35.89±12.01**	**34.40±17.58**	**29.26±18.82**
8/17/2011	**28.15±7.58**	**30.01±9.98**	**33.54±5.12**	**60.02±31.79**
8/30/2011	**37.82±13.19**	**23.70±13.94**	**48.07±1.22**	**58.47±3.07**
9/20/2011	21.65±1.66	18.63±8.73	26.26±5.99	27.16±9.36
10/4/2011	2.11±0.48	2.61±0.13	1.10±0.77	2.23±0.14
10/18/2011	5.88±0.50	5.48±0.16	7.062±0.16	4.74±0.44
11/8/2011	30.59±1.61	31.09±0.78	32.48±2.12	23.08±1.07

Note: bolded values indicate period without aeration

Comparison of DWA Chl-*a* concentrations for both years (Figure 32) show that Chl-*a* concentrations were higher when lake was aerated. The Wilcoxon Mann-Whitney's test confirmed that a significantly difference between aerated and non-aerated period occur when lake was aerate (p=0.04, Table E109). Higher Chl-*a* concentrations during aerated period were coincident with higher TDIN and SRP (Figure 16 and 21).

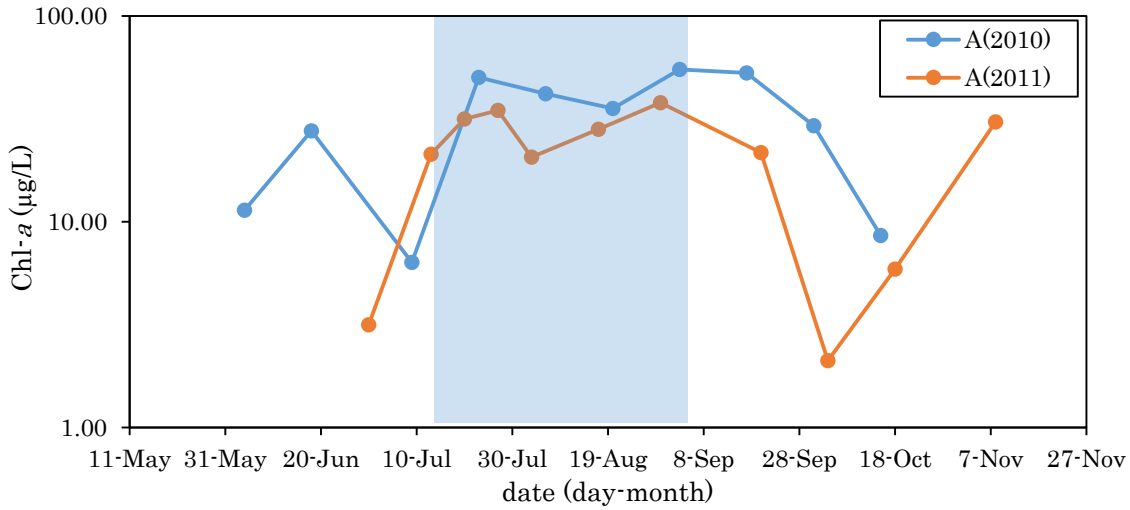

Figure 32. Depth-weighted average concentrations Chl-*a* at Site A: 2010 with aeration during entire period and 2011 without artificial aeration in shaded area.

4.5. Discussion

The main purpose of artificial aeration in the HMD was to eliminate summer stratification and improve vertical circulation of water, thereby increasing oxygen transfer from surface to bottom layers, thereby eliminating anoxic condition in the bottom of reservoir. The lack of differences in vertical temperature profiles indicate that aeration was effective on eliminating thermo-stratification. The water temperature was basically the same among the sites, indicating that the entire impoundment was well mixed. DO data showed that aeration in the HMD increased DO levels in the bottom layers above 4.5 mg/L in the reservoir during summer months and eliminated anoxic conditions near the bottom of the impoundment. Therefore, the mixing generated from aeration improved DO transfer from surface layers to the bottom thereby eliminating anoxic condition on the bottom the HMD. However, observed decreases of DO concentrations with depth imply a higher DO consumption in the bottom of the reservoir as a result of chemical and biological reactions (Müller et al. 2002; Lorke et al., 2003). Due to the higher organic content in the sediments found in the HMD oxygen is rapidly consumed at the sediment surface

The first aim of this study was to determine how artificial aeration would affect sediment nutrients release. Analyses of conductivity data show that dissolved salts were gradually and continuously added in the reservoir. Lack of differences of conductivity between depths and sites indicate that the entire reservoir was well mixed in terms of dissolved salts due to aeration. On the other hand, the faster rate of increasing of conductivity in the bottom layer is evidence that the sediments are the major source contaminants in the reservoir. Further analyses of nutrients reveal that sediments are identified as the major nutrient source in the HMD. The results of this study demonstrate that establishment of oxic condition due to aeration altered nutrient release in the HMD.

Aeration was found to be effective in reducing sediment nutrient release, especially release of orthophosphate. Phosphorous flux from sediments was reduced by nearly 50% under aerated conditions. This reduction of P was because increased DO concentration (higher redox potential) in water-sediment interface inhibited the release of a metal bound phosphate. As found by Einsele (1936) and Mortimer (1941, 1942) under aerobic conditions, Fe becomes oxidized and forms iron-(hydr)oxydes (FeOOH) that precipitates in the bottom of the reservoir. Phosphorus also reacts with Al^{3+}, Ca^{2+}, Fe^{2+}, or Fe^{3+} to from precipitates (Böstrom, 1988; Søndergaard, 2001; Christophoridis & Fyiantos, 2006) can also sorb to surfaces of Fe^{3+} and Al(hydr)oxide , calcite, and clays (Sondergaard, 2001). Likewise, lab experiments (Wang et al, 2008; Chen et al, 2011; Wu et al, 2014) also reported that increased DO on sediments-water interface reduced P release.

However, although the sediment-P released was significantly reduced, due to aeration in the HMD, the sediment P-release was not permanently buried in the sediments and thus, has no lasting effect on the tropic status of the reservoir. The observed gradual increase of TP and SRP concentrations during aeration in the HMD demonstrate that a

significant amount of P was released from sediments. Long-term experimental studies of aeration and destratification (Moosmann et al, 2006; Schauser & Chorus, 2007) reveal similar results. Based on the data of more than 10-year long experiments on the effect of hypolimnetic aeration, Gächter and Wehrli (1998) declared, "oxygenation is no solution to fight P pollution." The high rates of organic matter sedimentation exhausting DO and exceeding the P retention capacity of the sediment after diagenesis were pointed as a main reason for the limiting success of oxygenation to prevent P-release from sediments.

Numerous studies clearly demonstrate that P is mobilized in the decomposition of sediment organic matter, which also result in a significant release of P to the overlying water column (Gächter & Meyer, 1993; Chróst & Siuda, 2006; Chen at al, 2011). These findings suggest that release of P, as well as N, by biological degradation of organic sediment matter was not affected by changes in the oxygen levels in the HMD. Decomposition of organic matter occurs under anaerobic and aerobic conditions (Deinema et al, 1985; Wentzel et al, 1991). However, studies revealed that aerobic decomposition of organic matter is faster (Kristensen et al, 1995; Geurts et al., 2010). Therefore, it could be concluded that the artificial aeration improved the condition under which decomposition could proceed at higher rates, which in turn results in P release. These findings are confirmed by the observed gradual increase of SRP in the HMD.

Rates of decomposition of the organic matter depends on organic matter origin and age (Chróst & Siuda, 2006; Fenchel et al, 2012). In the eutrophic lakes and reservoirs, like the HMD, a substantial part of sediments organic matter is produced by phytoplankton that settles from the water column and decompose within the sediments (Anderson & Lastein, 1981; Kleeberg, 2002; Eckert et al, 2003; Reitzel et al, 2007). That internally produced organic matter would be easily decomposed by microbes (Kristensen & Holmer;

2001; Burdige, 2007), which subsequently results in inorganic P release in overlying water (Wilczek et al, 2005; Liu et al, 2009; Chen, 2014). Decomposition experiments showed 70%, 31-95%, and 24% of P-released was due to decomposition of diatom, green algae, and Cyanobacteria cells, respectively (Tessenow, 1972; Chen et al, 2014). The contribution of benthic bacteria in nutrient release, coupled with enhanced decomposition of organic matter under oxic conditions, thus results in an increase sediment-P release in the overlying water column.

The gradual increase of SRP concentrations in the warmest months in the HMD, followed by a decrease in fall months suggest that P release is additionally affected by temperature. Other experimental studies have shown that the increases in water temperature result in increases of microbial decomposition of organic matter, thereby resulting in enhanced P release (Gächter et al, 1988; Jensen, 1992; Liu et al, 2009; Wu et al, 2014). In addition, solid samples of sediments of the HMD showed that organic content in the sediments was high, making the decomposition of organic matter a significant source of nutrients in the HMD. Increased water temperature in summer months and increased oxygen levels, due to aeration likely enhanced decomposition of organic matter.

The analysis of vertical nutrient and phytoplankton distribution show that during 2011, when reservoir was not aerated, reduced mixing resulted in accumulation of nutrients in the bottom of the reservoir, whereas phytoplankton accumulated on surface layers. As a result, phytoplankton and nutrients become vertically separated in the water column. Although the nutrients were released at higher rates from sediments under non-aerated condition, most of the released N and P were not available for phytoplankton. In contrast, P and N released from sediments were mixed due to aeration through the water column making them available for phytoplankton growth. Results from a number of field

studies also have observed positive effects of increasing mixing depth on the enhanced phytoplankton in lakes and reservoirs (Visser et al, 1996; Diehl et al, 2002). In addition, aeration dispersed phytoplankton deeper in the reservoir, which increased their access to the nutrients. Increased nutrient availability, due to aeration was confirmed by the significantly higher Chl-*a* concentrations when the reservoir was aerated. Thereafter, the higher nutrient availability, due to aeration, enhanced nutrient availability for phytoplankton growth. Artificial aeration was not able to reduce higher phytoplankton growth.

The observed gradual increase of P concentrations, as a result of aeration in comparison with lower TDIN, concentrations imply that (1) although a higher phytoplankton was observed in the reservoir, P was added to the water body at a faster rate than the uptake rate and was in excess, (2) N is a limiting nutrient for phytoplankton growth. The nitrogen limitation is further confirmed by TDIN:SRP ratio in the reservoir. The calculated TDIN:SRP ratio for both sampling seasons 2010 and 2011 was much below the optimum 7.2:1, which was much below the accepted optimal ratio for phytoplankton growth 7.2:1 (Redfield, 1934). In several studies, low N:P ratio was associated with excessive growth and frequent blooms of Cyanobacteria (Smith, 1983).

4.6. Conclusions

This chapter targeted the effect of artificial aeration on nutrient release rates and nutrient availability for the phytoplankton growth in an eutrophic reservoir.

- Sediment release of N and P (internal loading) is the major nutrient source in the reservoir.

- Although aeration was found effective in reducing sediment nutrient release (TP) by nearly 50%, it was not able to eliminate TP. Release of metal bound phosphate was inhibited by aerobic condition near sediment water interface.
- However, biological release of phosphate occurs under both aerobic and anoxic conditions. Higher biological degradation rates under aerobic conditions may cause increased sediment nutrient release.
- Well mixed chemical ingredients and mixing induced vertical distribution of phytoplankton make nutrients more available under aerated condition.
- Low TDIN and accumulation of SRP indicates that nitrogen is the limiting nutrient in the HMD.

CHAPTER 5. IMPACTS OF ARTIFICIAL AERATION ON NUTRIENT AVAILABILITY FOR PHYTOPLANKTON SEASONAL SUCCSESSION

5.1. Abstract

Artificial aeration is a common management technique used to destratify eutrophic lakes, increase dissolved oxygen concentrations, and reduce nutrient sediment release and phytoplankton growth. However, studies show inconclusive results about the effect of aeration on phytoplankton growth and factors that cause changes in phytoplankton diversity, and seasonal succession. The current study determines the effect of artificial an aeration on phytoplankton growth, seasonal variation, and diversity in artificially eutrophic lake. Samples for phytoplankton analyses were taken under aerated and non-aerated condition during the summer growing seasons of 2010 and 2011. Results show that the Chlorophyll-*a* and phytoplankton biovolume increased significantly as a result of aeration. Higher nutrient availability, caused by aeration, changed seasonal succession of diatoms and dinoflagellates by increasing and extending growth. Continuous P release in addition to the low nitrogen:phosphorus ratio will promote Cyanobacteria growth. Change in nutrient availability, due to aeration, is the most important factor changing seasonal phytoplankton structure in artificially aerated water bodies.

5.2. Introduction

Composition of phytoplankton population in lakes and reservoirs is comprises of different species which follow similar seasonal patterns (sequence) through the season every year. These regular seasonal patterns of replacement of species is usually referred as a seasonal phytoplankton succession (Wetzel, 2001; Reynolds, 2006; Mitch & Gosselink, 2007). Such successional sequence in phytoplankton composition can be expressed as seasonal changes in total biomass, species richness, and diversity. The main controlling

factors include temperature, light availability, thermo-stratification, nutrient availability, and biological interactions (competition and grazing by zooplankton) (Sommer, 1985; Reynolds, 2006). Since these factors may have a complex effect on phytoplankton growth, seasonal succession may vary from year to year, and season to season.

Seasonal succession of phytoplankton in correlation with physical and biological factors is summarized the Plankton Ecology Group (PEG) model. The model is based on years of observations and summarizes seasonal variations in phytoplankton and zooplankton in 24 sequential events (patterns) (Sommer et al., 1986). Succession in eutrophic lakes has two maxima, a spring of small, fast-growing algae and summer maxima of large, grazing-resistant slow-growing forms. The model is based upon the general trend of a spring bloom of small diatoms, followed by the progression during summer from large inedible colonial green algae to large diatoms, then large dinoflagellates and/or Cyanobacteria, and finally to nitrogen-fixing filamentous Cyanobacteria (Sommer et al., 1986).

Phytoplankton species are very sensitive to the changes in environment and deviation from typical phytoplankton succession, therefore, is used as an indicator for the aquatic systems health. Changes in phytoplankton succession and community structure are accepted as an essential feature in lake and reservoir trophic status assessment. In recent decades, eutrophication of the water bodies have resulted in increased phytoplankton growth, decreased phytoplankton diversity and shifts in typical phytoplankton population structure (Schindler, 2008). Eutrophic lakes have been associated with an increase and frequent blooms of Cyanobacteria (Oliver & Ganf, 2000; Paerl & Huisman, 2008; Schindler et al, 2008; Smith & Schindler, 2009). The common problems associated with high phytoplankton growth include increased water turbidity, decreased dissolved oxygen (DO)

concentration, and even complete consumption of DO on the bottom of the lake as a result of decomposition of organic matter. The anoxic condition in lake ecosystems usually results in fish kill in midsummer, creates offensive odor and taste, and reduces overall aesthetics of water bodies. Moreover, some Cyanobacteria produce harmful toxins that cause increased health risk and rising cost of water treatment. Therefore, eutrophication degrades water quality and more important, negatively affects recreational and other designated uses of water bodies such as drinking water supply and irrigation (Schindler et al., 2008).

Artificial aeration has been commonly employed as a management technique with the purpose to eliminate thermal stratification and improve circulation in lakes and reservoirs. The enhanced circulation in turn stimulates oxygen transfer in the lakes and increases DO concentrations. It is well accepted that maintaining oxic condition on the bottom of reservoirs could reduce nutrient release from sediments (internal loading); especially on P release by forming metal, specifically iron-oxide precipitates (Einsele, 1936; Mortimer, 1941, 1942). In addition, since the P is widely accepted as a limiting factor for primary productivity in freshwater ecosystems and it is believe that increasing DO in the bottom of lakes and reservoirs may reduce P release from sediments, artificial aeration has been adopted as a method for reducing phytoplankton growth (Smith at al., 2002; Havens & Walker, 2002; Sterner, 2008).

Some studies demonstrate that aeration increased total phytoplankton population and phytoplankton composition shifted from Cyanobacteria to flagellates, green algae and diatoms (Visser et al., 1996; Heo & Kim, 2004; Jungo et al., 2001). These changes in phytoplankton biomass and composition contributed to the mixing caused by aeration, which destroyed buoyancy regulation of Cyanobacteria (Visser et al., 1996). Thus, limited vertical migration and buoyancy was no longer an advantage of Cyanobacteria. However,

increased mixing favored growth of other species like diatoms and green algae (Visser et al., 1996; Jungo et al., 2001). In addition, Chl-*a*, calculated as determined per m^2 increased. Similar results have been reported by Heo and Kim (2004). In addition to the mixing, the change in phytoplankton community was believed to be caused by competition for light. Although in all these studies showed that aeration did not affect Total Phosphorus (TP) concentrations, the increased Chl-a concentrations and changes in phytoplankton structure and diversity suggest that mixing generated from artificial aeration likely changed nutrient concentrations in reservoirs. Even though Heo and Kim (2004) pointed out that the artificial mixing may extend the natural spring mixing, they did not contribute a possible change in nutrient concentrations.

Likewise, results from a separate study conducted by Bürgi et al. (2002) show that in addition to increased total phytoplankton biomass, as a result of aeration, the diversity of phytoplankton increased. Although the authors reported that aeration reduced P loading, the phytoplankton growth was not reduced and changes in phytoplankton diversity due to changes in nutrient availability were not clearly explained. The opposite effect of artificial aeration on phytoplankton succession and dominance of the genera was observed when the phytoplankton community in an artificially aerated reservoir was compared with two adjacent naturally mixed lakes (Burford & O'Donohue, 2006). Results from the study show that artificial aeration not only expanded the growth of Cyanobacteria in time but also shifted the Cyanobacteria peak earlier in time (Burford & O'Donohue, 2006). The changes in succession of Cyanobacteria in manipulated lake suggest that seasonal patterns of nutrients also changed. However, Cyanobacteria higher growth was only explained by better competition for light and nitrogen, and a high uptake rate and storage capacity of P. Failure of artificial aeration to reduce higher phytoplankton has been reported by

Lindenshmidt et al., (1997), Sherman et al. (2000), and Antenucci et al. (2005). In most of these studies, the change in seasonal succession in terms of diversity of phytoplankton due to aeration has been poorly investigated and discussed. The mixed results from all the studies demonstrate inconclusive evidence of the effect of the artificial aeration on phytoplankton seasonal succession.

For years, nitrogen (N) and phosphorus (P) usually are invoked as limiting macro nutrients controlling phytoplankton growth in lakes and reservoirs (Hutchinson, 1967; Tilman, 1972). Redfield noted (1958) that phytoplankton requites stoichiometric N:P ratio of 7.2:1 by weight. The 7.2:1 had been widely accepted as optimal ratio for the phytoplankton growth, and deviation from this ratio indicates either N or P will be the limiting factor for the growth. The ratio below 7.2:1 indicates nitrogen limitation, while ratio above 7.2:1 indicates that the P is the limiting factor for the growth. This ratio, often referred as "Redfield ratio", is widely used to determine nutrient balance and the limiting nutrient in a lake. Based on this stoichiometric relationship, amount of phytoplankton that may grow is controlled by the least available nutrient, N or P. As nutrient availability changes, in terms of both N to P concentrations, the nutrient condition may favor the growth of certain species and result in more growth and dominance of those species (Dortch, 1990; Vrede et al., 2009). Prediction of competitive dominance of each phytoplankton species was based on the results of analyses of nutrient kinetics under condition of P and/or N limitation (Helterman & Toetz, 1984; Sommer, 1986; De Nobel et al, 1997; Degerholm et al., 2006). However, changing of nutrient release rates and availability, due to aeration, as a key factor for phytoplankton growth and community changes was underestimated and not clearly applied.

Artificial aeration was installed in a small eutrophic reservoir in North Dakota, managed by North Dakota Game and Fish Department (NDGFD) with the intention to increase DO concentration in the hypolimnion. NDGFD also believed that increasing DO on the sediment-water interface might result in reduction of internal P-loading and phytoplankton growth. Previous research conducted in 2008 to evaluate effectiveness of artificial aeration suggested that the artificial aeration increased DO concentrations and prevented anoxic conditions near the bottom of the reservoir (Overmoe, 2008). Visual, qualitative observations suggested that high phytoplankton growth continued in the reservoir, but samples for phytoplankton biomass and speciation analyses were not taken. In the current research (CHAPTER 4), as clearly demonstrated in CHAPTER 4, that aeration made nutrients more available for the phytoplankton growth. To address and better understand the effect of artificial aeration on phytoplankton seasonal succession through changing nutrient availability, this current study was conducted in an artificially aerated lake over two consecutive years during the summer growing seasons.

5.3. Methodology

5.3.1. Sampling site, period and frequency

For detailed description and characteristics of the study site and sampling sites, as well as frequency of sampling and duration of the sampling period, please see CHAPTER 3.

5.3.2. Phytoplankton sampling and sample analyses

Phytoplankton enumeration, biovolume, and Chl-*a* sampling and analyses were used to quantify the effect of artificial aeration on phytoplankton seasonal succession, abundance, diversity, and species composition. Water samples for Chl-*a* and phytoplankton analyses were taken under two consecutive years during the summer growing seasons of 2010 and 2011. The time schedule and time frequency followed the same sampling schedule

as that of nutrients sampling schedule for both years. The sampling depths were designed to determine the effect of artificial aeration on vertical distribution of phytoplankton and based on a typical phytoplankton distribution observed in temperate lakes: Surface, Secchi depth (the depth of maximum light penetration), 2×Secchi depth (an approximate estimation of the maximum depth of euphotic zone at which 1% of the incident light penetrates). The 1.5m and 0.5m from the bottom was added to determine vertical extend at which phytoplankton would be distributed.

5.3.2.1. *Chlorophyll-a*

Water samples for Chl-*a* extraction were taken with a vertical Van Dorn water sampler and filtered in the field through Whatman GF/F- 0.7 µm pore size glass fiber filters. The pigment ethanol extraction method (Lorenzen, 1967; Sartory et al., 1984) and spectrophotometric determination were performed within 24 h after sampling in Environmental Lab at NDSU.

5.3.2.2. *Phytoplankton identification, counting, and biovolume determination*

500 ml water samples for phytoplankton identification, enumeration, and biovolume determination analysis were preserved with Lugol's acid solutions in the field. The phytoplankton species were counted and identified under Inverted Microscopes (*Leica and Zeiss)*. Phytoplankton were identified to genus level. (Detailed procedure of phytoplankton counting and identification is included in APPENDIX C).

In this study the Methodology for phytoplankton biovolume estimation was updated and developed. All measurements needed for biovolume determination were taken using *ImageProPlus* 5.0 image analysis software. The biovolume of each phytoplankton unit (cell, colony, or filament) was determined by multiplying the unit volume by the abundance of these units in the sample. The biovolume of each unit was determined by applying one of

the three developed methods: 1) area and depth method, 2) cross section area and length method, and 3) biovolume based on commonly accepted geometry.(Detailed procedure for phytoplankton biovolume is included in APPENDIX D).

5.3.3. Data processing

Depth-weighted average (DWA). Since the depths at which water samples for Chl-*a* and phytoplankton analyses were taken vary and were not equally distributed over the water column, the depth-weighted average method was used to calculate average concentrations of phytoplankton. To describe overall phytoplankton seasonal succession the variations depth weighted averaged biovolumes were plotted together. To represent clear time variation of phytoplankton classes, abundant classes are presented separately, while less abundant classes are grouped together and presented as "Other classes". Data for biovolume variation are presented in a logarithmic scale. The relative biovolume is calculated by dividing biovolume of a genus (by any measure) by the total biovolume of all genus combined and is expressed as a percentage. For detailed observation on the effect of aeration on phytoplankton genera, each class is described separately later in this chapter. (Detailed procedure of DWA is included in APPENDIX D).

5.3.4. Statistical analysis

One-way ANOVA analysis was performed to test the effect of artificial aeration on nutrient and phytoplankton distribution between sampling depths and throughout sampling sites. For this research, a p-value of less than 0.05 was used to determine statistical significance. Tukey's (HSD) test is a post-hoc test, which is performed after an ANOVA test to determine which groups in the sample differ. Wilcoxon Mann-Whitney's (WMW) non parametric test was used to compare the differences between the DWA nutrient concentrations (TDIN and SRP) and phytoplankton (Chl-*a* and biovolume) data

between period without aeration in 2011 with the similar period in 2010 when the lake was aerated. All statistical analyses were conducted using the SAS statistical program.

Population analyses including diversity indices, evenness and diversity, were applied in this research to evaluate the effects of artificial aeration on genera composition. Phytoplankton diversity was determined using Shannon-Weaver 's Diversity Index (H') and Pielou's Evenness Index was used to determine evenness. The Shannon-Weaver Diversity index is applied to biological systems for calculating diversity (Shannon & Weaver, 1949)..

$$H' = -\sum \left(\frac{n_i}{N}\right) * ln\left(\frac{n_i}{N}\right) \qquad \text{(Equation 5.1)}$$

where: ni-the abundance of species i,
N-the total number of individuals in the community

The maximum diversity of a phytoplankton community occurs when all species are equally abundant in numbers or contribute equally to the total number of individuals. Maximum diversity (H_{max}) is given by:

$$H_{max} = ln\, S \qquad \text{(Equation 5.1)}$$

where: S -the total number of species of a community.

The ratio of Shannon index to the maximum diversity value gives the Pielou's Evenness Index. The values range between 0 – 1, where the close the value to 1 the more even the distribution of phytoplankton (Pielou, 1966).

$$E = \frac{H'}{H_{max}} \qquad \text{(Equation 5.2)}$$

where: H′- Shannon-Weaver 's Diversity Index, and H_{max}

The dominant algal group was identified as one that comprised at least 50% of the total phytoplankton population.

5.4. Results

5.4.1. Effect of artificial aeration on temperature

The main purpose of aeration in the HMD, as in CHAPTER 4, was to eliminate summer stratification and oxygen concentrations in the reservoir. Variation in water temperature during 2010 and 2011 (Figure 6 and 7, CHAPTER 4) with higher values in the summer and lower values in the spring and autumn, is typical of temperate regions. The lack of difference in vertical water temperature distribution in 2010 show that the water column was mixed to the bottom of the reservoir due to aeration (Figure 7). The uniform temperature condition also suggests that aeration successfully eliminated thermal stratification in the deepest part of the reservoir. No significant differences in vertical water temperature distributions among the sites were observed, indicating that the water temperature was the same throughout the reservoir (Table 3, CHAPTER 4). When aeration was stopped in the summer of 2011 the water temperature differences between the surface and bottom water layers increased up to 2˚C, indicating that stratification was established in the reservoir (Figure 8, CHAPTER 4).

5.4.2. Phytoplankton identification

The phytoplankton abundance and species composition variations were observed during summer growing seasons in two consecutive years, 2010 and 2011. During both years, 45 taxa from eight classes of phytoplankton were identified (Table 20).

Table 20. Phytoplankton classes and genera identified in HMD, 2010 and 2011

Class	Genera
Bacillariophyceae (diatoms)	*Asterionella* sp. *Aulacoseira* sp., *Cymbella* sp., *Fragilaria* sp., *Gomphonema* sp., *Navicula* sp., *Stephanodiscus* sp., *Synedra* sp., *Cyclotella* sp., *Cocconeis* sp., *Gyrosigma* sp., Unknown diatoms (includes mixed genus belongs to class Bacillariophyceae)
Dinophyceae (dinoflagelates)	*Peridinium* sp., Ceratium sp, and Gymnodinium sp.
Cyanophyceae (Cyanobacteria, blue green)	*Anabaena* sp., *Aphanizomenon* sp., *Lyngbya* sp., *Microcystis* sp., *Oscillatoria* sp., *Gomphosphaeria* sp.
Chlorophyceae (green algae)	*Coelastrum* sp, *Ankyra* sp., *Cosmarium* sp., *Characium* sp., *Oocystis* sp., *Scenedesmus* sp. *Staurastrum* sp., *Pediastrum* sp., *Quadrigulla* sp., *Elalcantothrix* sp. *Pandorina* sp., *Actinastrum* sp.
Cryptophyceae	*Cryptomonas* sp.
Chrysophyceae	*Dinobryon* sp.
Euglenophyceae	*Euglena* sp., *Phacus* sp., and *Lipocinclis* sp.
Synurophyceae	*Mallomonas* sp.

5.4.3. Effect of artificial aeration on phytoplankton seasonal succession

Figures 33 and 34 give an overview of variations of total phytoplankton biovolume differentiated by classes during 2010 and 2012, respectively. In 2010, when reservoir was aerated, variations in DWA biovolumes of phytoplankton classes over time in the HMD show succession patterns. Diatoms' DWA biovolume increased from mid-June to the end of June in 2010 (Figure 33, a). At the end of June, diatoms accounted for 80% of the total phytoplankton community (Figure 33, b). Cryptophyceae DWA was high and co–dominated with diatoms at the beginning of June (Figure 33, a and b). At the beginning of July, diatoms' and Cryptophyceae DWA biovolumes decreased and remained relatively constant until the beginning of September when slightly increased, each comprising about 5% of the total DWA biovolume. After diatoms and Cryptophyceae decreased, dinoflagellates DWA biovolume increased and remained relatively constant and relatively higher than other classes from mid–summer to the end of September when dinoflagellates rapidly decreased (Figure 33 a).

Depth-weighted averaged biovolume of Cyanobacteria also showed increase in middle of the summer (Figure 33, a). However, Cyanobacteria comprised less than 10% of the total phytoplankton DWA biovolume. Chlorophyceae DWA biovolume remained relatively constant over the sampling season most of times were below 5% of the total DWA biovolume (Figure 33, b). Chlorophyceae. Chrysophyceae, Euglenophyceae, and Synurophyceae, as a group remained relatively low in terms of DWA biovolume and relative biovolume.

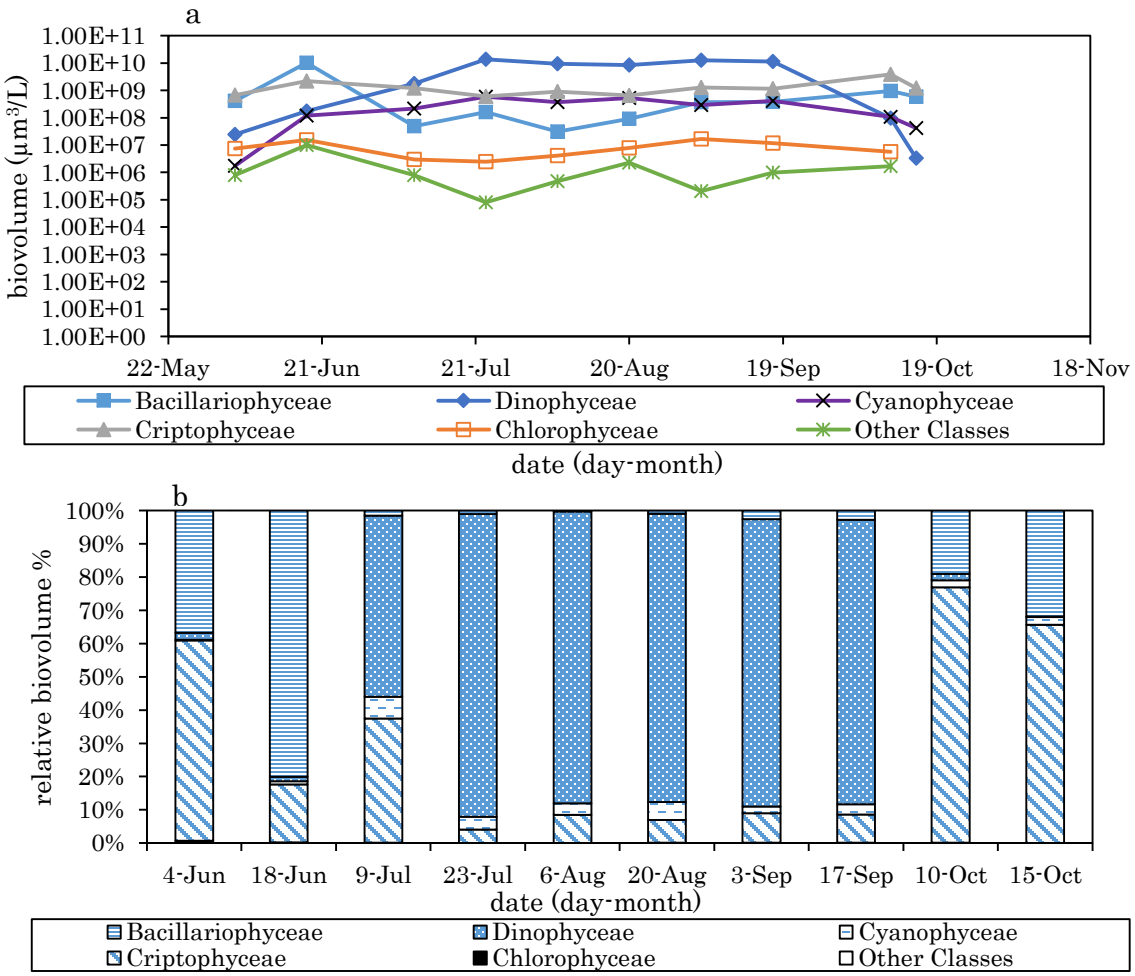

Figure 33. Phytoplankton classes at Site A (2010) with aeration during entire period (a) DWA biovolume and (b) relative DWA biovolume.

At the end of June 2011, variations of biovolume also showed a seasonal succession but were quite different from succession of phytoplankton during 2010. Similar to 2010,

when reservoir was aerated, population of diatoms was present in reservoir and comprised 89% of the total phytoplankton biovolume (Figure 34, a and b). Meanwhile, increase of Cyanobacteria DWA indicated faster growth and at the beginning of July comprised 87% of the total phytoplankton biovolume (Figure 34, b). On July 13th, artificial aeration was stopped. In the next two weeks, Cyanobacteria continued to grow and was still the dominant class (90-96%). However, at the end of July 2011, Cyanobacteria rapidly decreased. After the decline of Cyanobacteria, dinoflagellates increased gradually in their DWA biovolume. In August, dinoflagellates comprised 63 to 76% of the total DWA (Figure 34, b). An increase of Class Cryptophyceae also was observed during period without aeration. From the end of August to October, most of the phytoplankton classes, except Cryptophyceae decreased. In the end of the sampling season (November), Cryptophyceae dominated over the rest of phytoplankton classes at almost 100% (Figure 34, b).

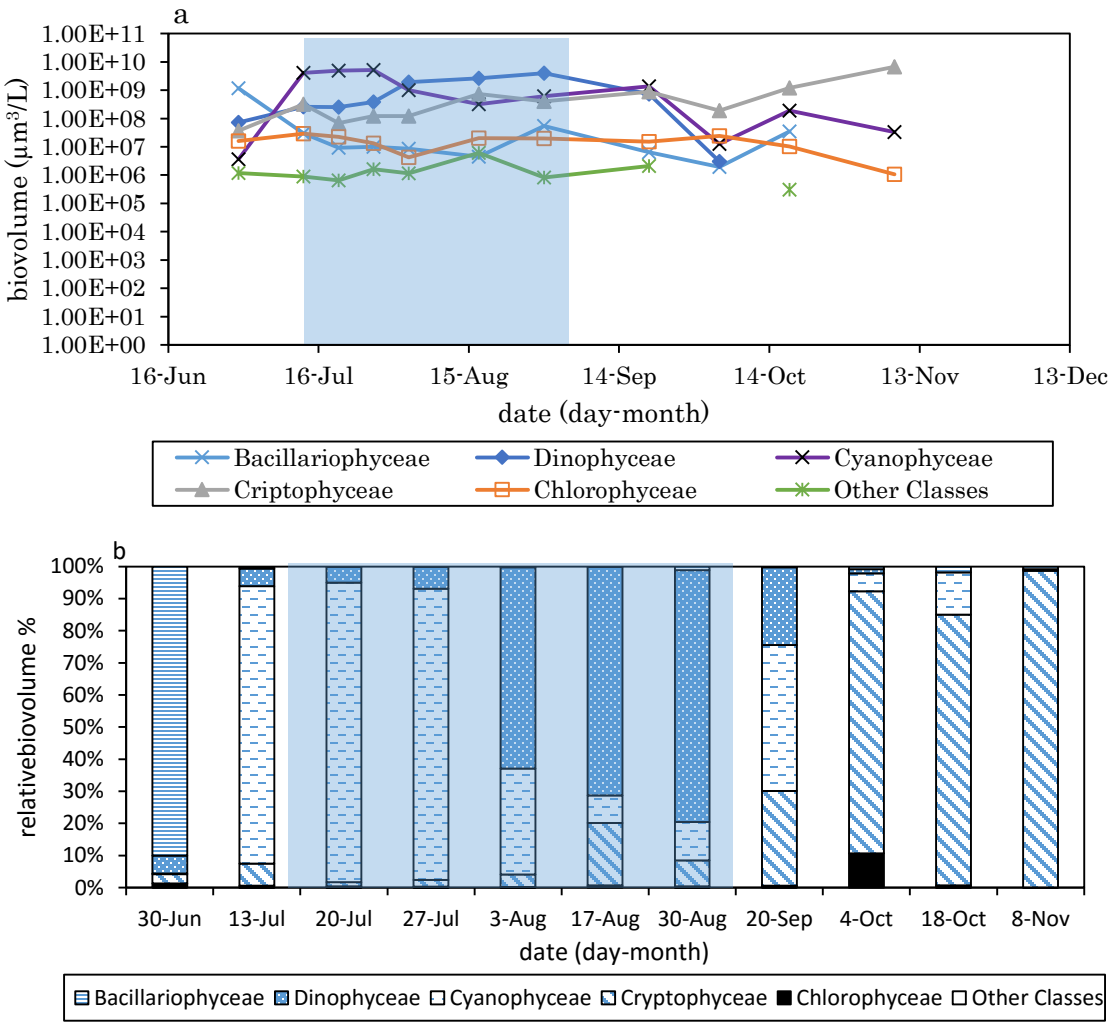

Figure 34. Phytoplankton classes at Site A (2010) without aeration in shaded area (a) DWA biovolume and (b) relative biovolume.

5.4.4. Effect of artificial aeration on Bacillariophyceae (diatom)

5.4.4.1. *Effect of artificial aeration on total diatom's population*

Variations in DWA biovolume of diatoms in the HMD in 2010 and 2011 at Site A are shown in Figure 35. For both years, diatoms' distributions show a similar pattern in DWA biovolume variations over time with a higher biovolume in June, followed by a decrease in summer months, before increasing again in fall months. The observed decrease in 2011 was coincident with the stopping of aeration.

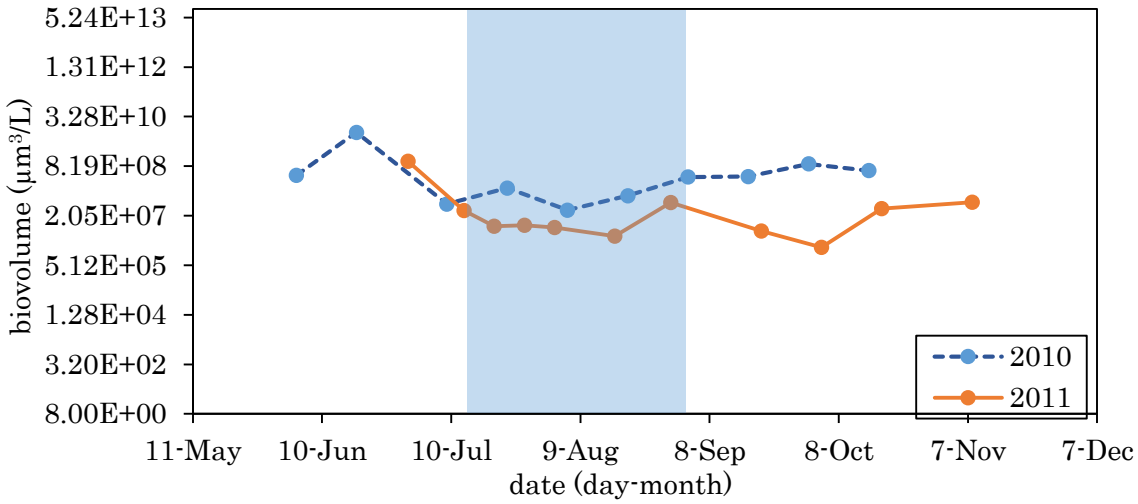

Figure 35. Depth-weighted average biovolume of diatoms at Site A: 2010 with aeration during entire period and 2011 without artificial aeration in shaded area.

Analysis of diatoms' DWA biovolumes shows that the diatoms biovolume in 2010, when lake was aerated, was to 4 to 20 times higher than in 2011, when the reservoir was non-artificially aerated. Although aeration was resumed in fall in 2011, diatom biovolume was much lower compared to the same period in 2010. Results from WMW test show significant differences in diatom's DWA biovolumes, when the lake was aerated ($p=0.04$, Table 110). These results suggest that aeration increased and expanded diatoms growth in summer months.

Diatoms in the HMD followed a seasonal succession typical for temperate lakes. Primary factors favoring diatoms growth in spring and fall include cooler temperatures, turbulent mixing, and higher nutrient (N, P, and Si) concentrations (Köster & Pienitz, 2006; Ferris & Lehman, 2007; Lehman et al., 2007). According to nutrient kinetic parameters included in Table 1 (CHAPTER 2), diatoms have relatively higher maximum growth rates (μ_m) and higher specific nutrient uptake rates (V_m) for N and P than the rest of the phytoplankton groups. Their higher growth rates make diatoms good nutrient competitors, which determine their dominance in spring and fall when the nutrient

concentrations are usually higher. Several studies also demonstrated that increased mixing, due to artificial aeration in lakes, increased diatoms' population growth (Visser et al., 1996; Lindenshmidt & Chorus, 1997; Heo & Kim, 2004; Antenucci et al., 2006; Becher et al., 2006; Goldenberg & Lehman, 2012). Mixing of the water column has been found beneficial to diatoms to keep them suspended in water column (Reynolds, 2006). In addition, the higher DWA biovolume of diatoms in 2010 matched the observed increase of nutrient availability in the water column. However, stopping of aeration and related decrease of the mixing and nutrient availability resulted in decrease of diatoms in the HMD. Decline of diatoms caused by nutrient limitation during periods of stratification in summer months was reported many times (Egge & Aksnes, 1992; Furnas, 1990; Sommer, 1985). Reduced mixing of water column usually leads to high losses by sinking (Reynolds, 1984; Sommer 1987).

5.4.4.2. *Effect of artificial aeration on vertical distribution of diatoms*

Analysis of vertical distribution of diatom's biovolume at Site A shows that during 2010, when aeration was in operation, the diatoms were dispersed in deeper layers in the impoundment (Figure 36). ANOVA analysis comparing differences of diatom distribution across the sampling depths confirmed no significant differences ($p=0.99$, Table E64). Similar to Site A, no significant differences between sampling depths were found at Site B ($p=0.86$), C ($p=0.71$), or D ($p=0.46$) (Tables E65, E66, and E67, respectively). These results indicate that the diatoms were dispersed with the depth due to aeration.

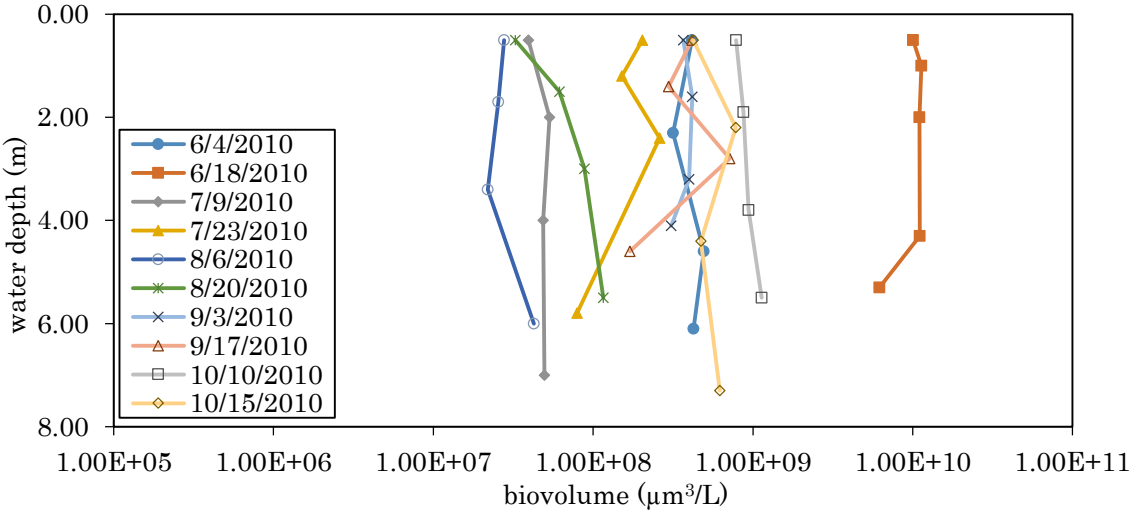

Figure 36. Vertical variation in biovolume of diatoms at Site A (2010) with aeration in entire period

In 2011, during period withut aeration, the diatoms were obviously not uniformly distributed throughout the water column (Figure 37). A week after aeration was turned off a relatively higher biovolume was observed at the bottom of the reservoir, which indicates that most of diatoms probably settled on the bottom of the reservoir after the mixing from aeration were reduced. Over next two weeks, the increased biovolume on the surface indicate that diatoms accumulate at 2 × Secchi depth or on the surface, which could be related to their light requirements (Davey & Heaney, 1989). However, for the whole period without aeration, ANOVA results showed no significant difference of diatom distribution over depths at Site A ($p=0.94$, Table E68). Similarly, no significant differences with depths were found at Sites B ($p=0.94$), C ($p=0.43$), or D ($p=0.06$) (Tables E69, E70, and E71, respectively).

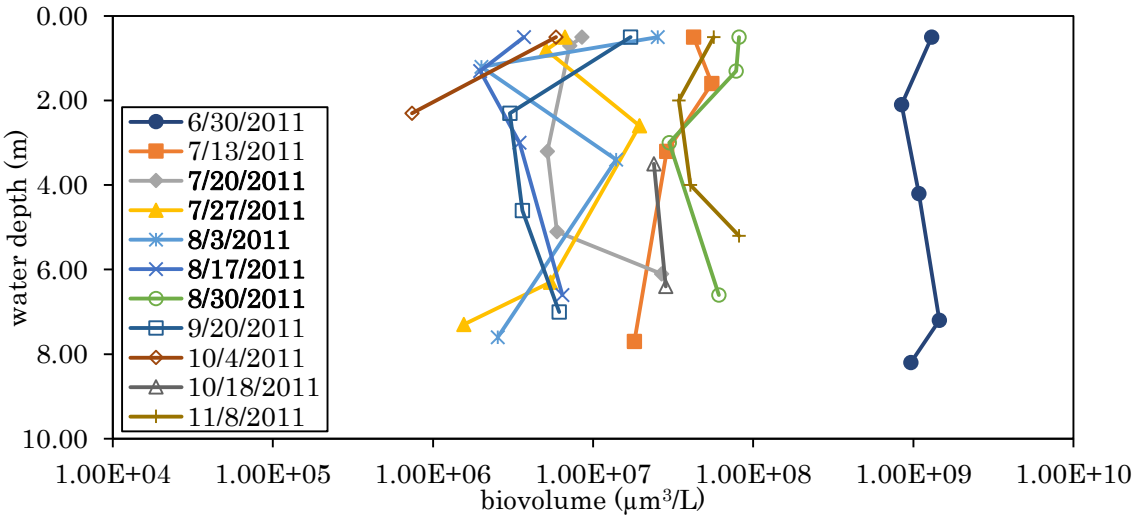

Figure 37. Vertical variation in biovolume of diatoms at Site A (2011) without aeration in bolded dates in the legend.

5.4.4.3. *Effect of artificial aeration on aeration of diatom between the sites*

Depth weighted average biovolumes of diatoms are for all sites presented in Table 21. Diatoms distribution was the same at all sites in the reservoir.

Table 21. Diatoms' depth-weighted average biovolume and Standard deviation (STD), 2010

date (mo/day/yr)	diatoms' biovolume (average ± STD), µm³/L			
	Site A	Site B	Site C	Site D
6/4/2010	4.10E+08 (7.19E+07)	2.08E+08 (4.17E+08)	2.33E+08 (2.26E+08)	3.32E+08 (3.78E+08)
6/18/2010	1.01E+10 (2.05E+09)	9.68E+09 (5.98E+10)	7.21E+09 (6.34E+09)	2.62E+09 (5.76E+09)
7/9/2010	4.86E+07 (4.70E+06)	3.25E+08 (1.13E+09)	3.69E+08 (2.24E+08)	3.25E+08 (4.95E+08)
7/23/2010	1.60E+08 (8.87E+07)	2.21E+08 (2.01E+08)	3.50E+08 (6.54E+08)	9.81E+07 (3.59E+08)
8/6/2010	3.08E+07 (9.93E+06)	2.91E+07 (1.27E+07)	2.10E+08 (2.52E+08)	1.46E+08 (8.75E+07)
8/20/2010	9.08E+07 (3.33E+07)	1.77E+08 (2.24E+08)	1.61E+08 (7.00E+07)	1.55E+08 (6.49E+07)
9/3/2010	3.66E+08 (5.08E+07)	4.31E+08 (4.73E+08)	3.55E+08 (2.58E+08)	3.29E+08 (1.44E+08)
9/17/2010	3.75E+08 (2.47E+08)	4.14E+08 (4.42E+08)	4.95E+08 (5.91E+08)	4.61E+08 (7.16E+08)
10/1/2010	9.61E+08 (1.47E+08)	1.05E+09 (9.10E+08)	5.84E+08 (1.14E+08)	6.76E+08 (4.82E+08)
10/15/2010	5.83E+08 (1.44E+08)	1.39E+09 (8.07E+09)		

In 2011, when the aeration was stopped, the DWA of diatom show that the distribution of diatoms was basically the same in the entire reservoir (Table 22).

Table 22. Diatoms' depth-weighted average biovolume and Standard deviation (STD), 2011

date (mo/day/yr)	diatoms' biovolume (average ± STD), $\mu m^3/L$			
	Site A	Site B	Site C	Site D
6/30/2011	1.17E+09 (2.48E+08)	2.30E+09 (5.93E+09)	1.35E+09 (1.81E+09)	8.95E+08 (1.10E+09)
7/13/2011	2.98E+07 (1.45E+07)	5.23E+08 (1.28E+09)	1.47E+08 (1.79E+08)	1.22E+08 (8.69E+07)
7/20/2011	**9.30E+06 8.31E+06**	**6.40E+07 (1.08E+08)**	**2.47E+07 (3.46E+07)**	**1.24E+07 (2.64E+07)**
7/27/2011	**9.92E+06 8.05E+06**	**5.01E+06 (1.47E+07)**	**3.80E+07 (5.78E+07)**	**1.73E+07 (1.29E+07)**
8/3/2011	**8.59E+06 8.48E+06**	**8.30E+07 (7.57E+07)**	**9.84E+06 (8.61E+06)**	**1.41E+07 (1.23E+07)**
8/17/2011	**4.49E+06 1.92E+06**	**2.78E+07 (1.10E+08)**	**2.29E+08 (5.08E+08)**	**9.22E+06 (1.37E+07)**
8/30/2011	**5.47E+07 (2.09E+07)**	**1.70E+08 (1.94E+08)**	**7.52E+06 (1.97E+07)**	**1.68E+07 (1.99E+07)**
9/20/2011	6.50E+06 5.45E+06	1.07E+07 (2.21E+07)	3.33E+07 (2.67E+07)	1.35E+07 (1.61E+07)
10/4/2011	1.94E+06 2.43E+06	6.62E+06 (1.45E+07)	1.15E+07 (8.34E+06)	8.79E+06 (9.23E+06)
10/18/2011	3.50E+07 5.71E+06	6.46E+07 (6.19E+07)	3.47E+07 (2.66E+07)	4.49E+07 (9.34E+07)
11/8/2011	5.52E+07 2.21E+07	4.79E+07 (7.86E+07)	2.05E+08 (1.77E+08)	2.10E+08 (2.38E+08)

Note: bolded values indicate period without aeration

5.4.4.4. *Effect of artificial aeration of diatoms' genera distribution*

A total of 11 genera of diatoms were identified in the HMD both years. In 2010, at Site A among the diatoms, *Fragilaria* sp. and *Stephanodiscus* sp. (Figure 38, a and b, respectively) were among the major genera in the HMD. In June 2010, *Fragilaria* sp. increased in biovolume (Figure 39, a), comprising 85-88% of the total diatom biovolume (Figure 39, b). On June 18th, the observed dominance of *Fragilaria* sp. coupled with a higher density of *Fragilaria* sp. (DWA biovolume 8.53×10^9 μm^3) indicated that a bloom occurred. After the observed bloom *Fragilaria* sp. biovolume decreased and was replaced by *Stephanodiscus* sp. for about a month (Figure 39, a), which accounted for about 60% of the

total diatom biovolume (Figure 39 b). Although the biovolume of *Fragilaria* sp. decreased in summer months, *Fragilaria* sp. was present in the HMD in the entire sampling period (Figure 39, a). In fall, *Fragilaria* sp. again increased in biovolume (Figure 39, b), consisting for more than 90% of the total diatom biovolume, which was coincident with a decreasing of temperatures in fall months. DWA biovolume for the rest of the observed diatom genera including *Asterionella* sp, *Aulacoseira* sp., *Cymbella* sp., *Synedra* sp. (Figure 40, a, b, and c, respectively), *Navicula* sp., *Cyclotella* sp., and *Gomphonema* sp. remained relatively low and without any clear variations in biovolume (Figure 39, a and b).

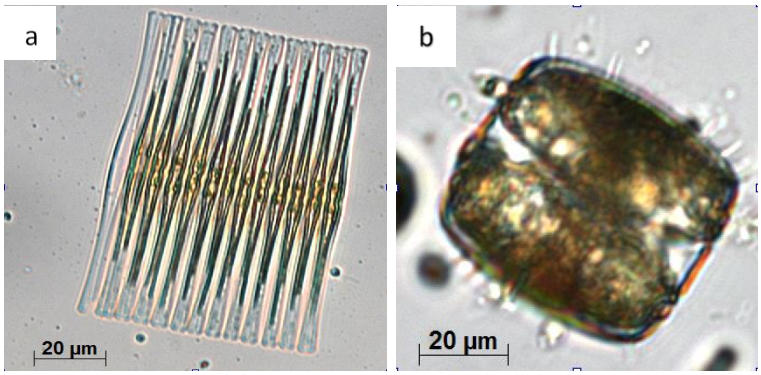

Figure 38. Bacillariophyceae genus (a) *Fragilaria* sp. and (b) *Stephanodiscus* sp.

Fragilaria sp., *Stephanodiscus* sp. and *Aulacoseira* sp. are among the typical genera found in spring in temperate lakes (Sommer, 1991; Interlandi et al., 1999; Arhonditsis et al., 2004, Mieleitner et al., 2008). The data analysis of diatoms' population in the HMD showed that artificial aeration did not change seasonal succession of these genera, but significantly increased their growth (Figure 35). The higher growth of diatom's genera in the HMD was coincident with the continuous addition of nutrients, especially P to the water column when reservoir was aerated (Figure 24, CHAPTER 4). It was confirmed that *Fragilaria* sp. and *Stephanodiscus* sp. could grow at P-rich environment (Kilham, 1986; Egge et al, 1992; Interlandi et al. 1999; Reynolds, 2006). *Stephanodiscus* sp. is also often identified as an early spring species and thus typically reaches its highest biomasses at low

temperatures, short day-length, and under more intense mixing (Sommer et al., 1986; Nicklisch et al., 2008; Shatwell et al., 2008). Therefore, observed gradual increase of P in addition to the mixing due to aeration was, able to support diatoms growth in the HMD.

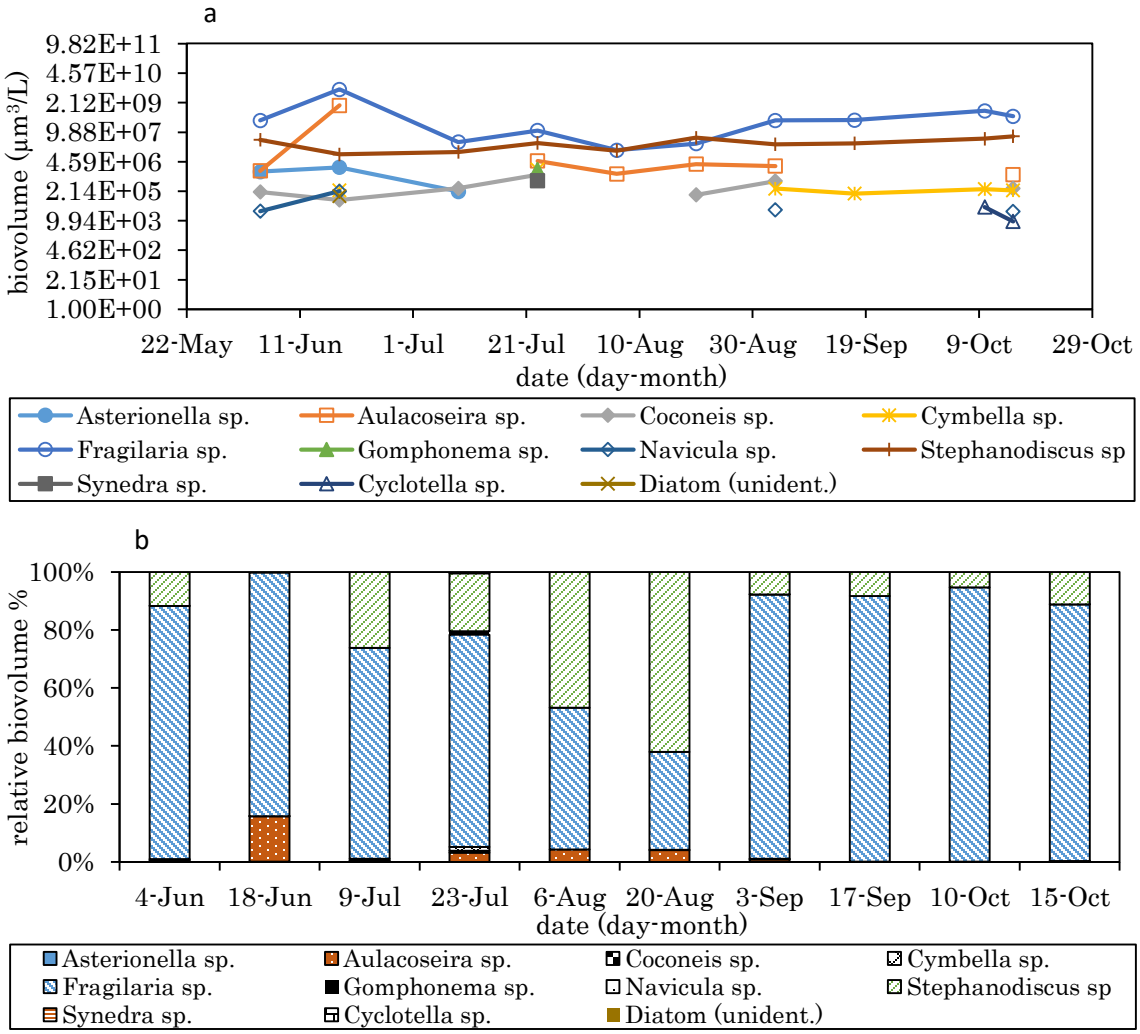

Figure 39. Diatoms' genera at Site A (2010) with aeration in entire period: (a) DWA biovolume and (b) relative biovolume.

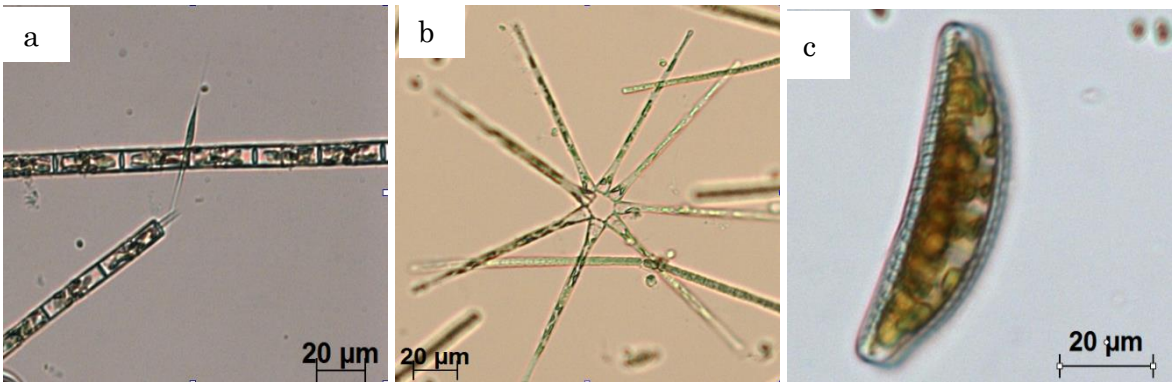

Figure 40.Diatoms genus (a) *Aulacoseira* sp., (b) *Asterionella* sp., and (c) *Cymbella* sp.

In June 2011, when the reservoir was aerated, *Fragilaria* sp. DWA biovolume was higher (Figure 41, a) accounting for 80-96% from the total diatoms' biovolume (Figure 41, b). When the aeration was stopped, variations of DWA biovolumes for the rest of diatom's genera differed from those described in 2010. After the mixing was stopped, as most of the diatoms, *Fragilaria* sp. biovolume decreased and instead of being replaced by *Stephanodiscus* sp., *Fragilaria* sp. was replaced by *Aulacoseira* sp. (Figure 41, a). *Aulacoseira* sp. increased slightly at the end of non-aerated period (Figure 41, a) comprising 95% of the total DWA diatoms' biovolume (Figure 41, b). Reduced mixing of water column usually results in a high losses by sinking (Reynolds 1984; Sommer 1987)

During the period without aeration in 2011, the decline of diatoms suggests that the required nutrients (N and P) become limited for their growth. In CHAPTER 4 was shown that after stopping of aeration, P and N accumulated in the bottom of reservoir and were less available for the phytoplankton growth. Over the next two weeks after the stratification was stopped although in relatively lower biovolume, *Fragilaria* sp. and *Stephanodiscus* sp. were still observed in the water column (Figure 41, a). *Stephanodiscus* sp. was the first genera decreased in biovolume, which has a relatively higher half-saturation constant for P and N than *Fragilaria sp.* (Table 1, CHAPTER 2). Egge (1998) also suggest that the diatoms are poor competitors for P. These results suggest that

Stephanodiscus sp. less competitive at limited N and P concentrations in the water, when reservoir was not aerated.

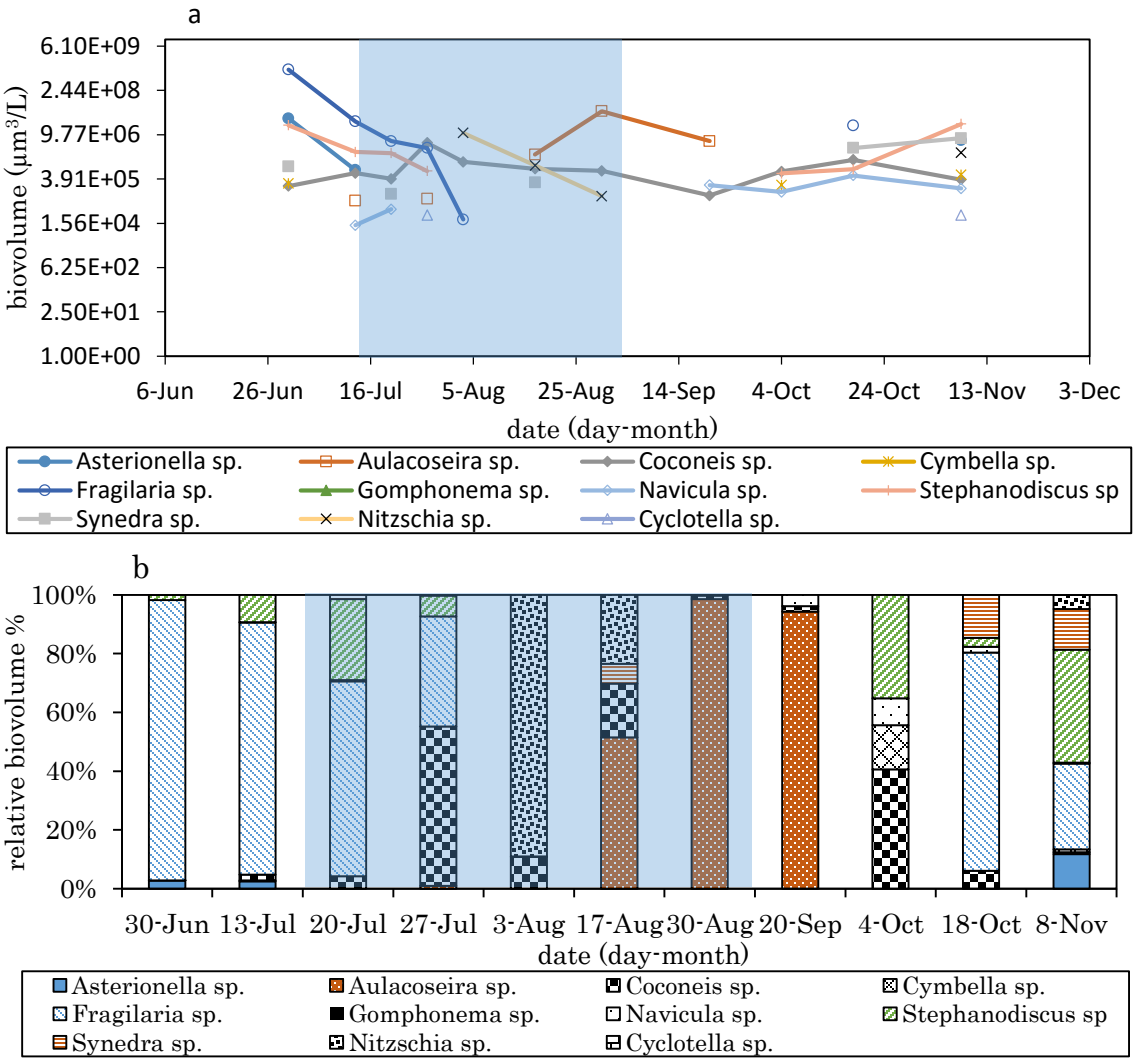

Figure 41. Diatom genera at Site A (2011) without aeration in shaded area: (a) DWA biovolume and (b) relative biovolume of diatoms genera

In addition to N and P, diatoms require dissolved silica (Si) to build their cells. Si usually becomes exhausted after a higher spring development of diatoms (Sommer, 1991). *Fragilaria* sp. have a higher half-saturation constant for Si (2.17 µM/L) than *Stephanodiscus* sp. (0.35 µM/L) (Donk & Kilham, 1990). These findings might explain why in the mid-summer, when lake was aerated and nutrient availability (N and P) were highest, *Stephanodiscus* sp. dominated over the diatoms. For the HMD we do not have data

for Si but replacement of these two species over time indicates that Si was still available but over time became limiting for those with a higher uptake rate. Decreased nutrient availability and reduced mixing caused a decline of diatoms after aeration was stopped.

5.4.5. Effect of artificial aeration on Dinophyceae (dinoflagellate)

5.4.5.1. *Effect of artificial aeration on total dinoflagellate population*

Variations in DWA biovolume of dinoflagellates in the HMD in 2010 and 2011 at Site A are shown in Figure 42. For both years, dinoflagellates biovolume increased and peaked in the summer months. In the HMD, DWA biovolume of dinoflagellates, similarly to diatoms, was 3 to 30 times higher during the artificially aerated period. Results from WMW test show significant differences in DWA biovolume of dinoflagellates between 2010 and 2011 ($p=0.02$, Table 111). Significantly higher dinoflagellates biovolume in the HMD was coincident with a higher nutrient availability when lake was aerated. In addition, dinoflagellates peaked earlier in 2010 when the nutrients were continuously added to the water column. Aeration did not change natural summer growth of dinoflagellates in the HMD, but increased and prolonged their growth in summer months.

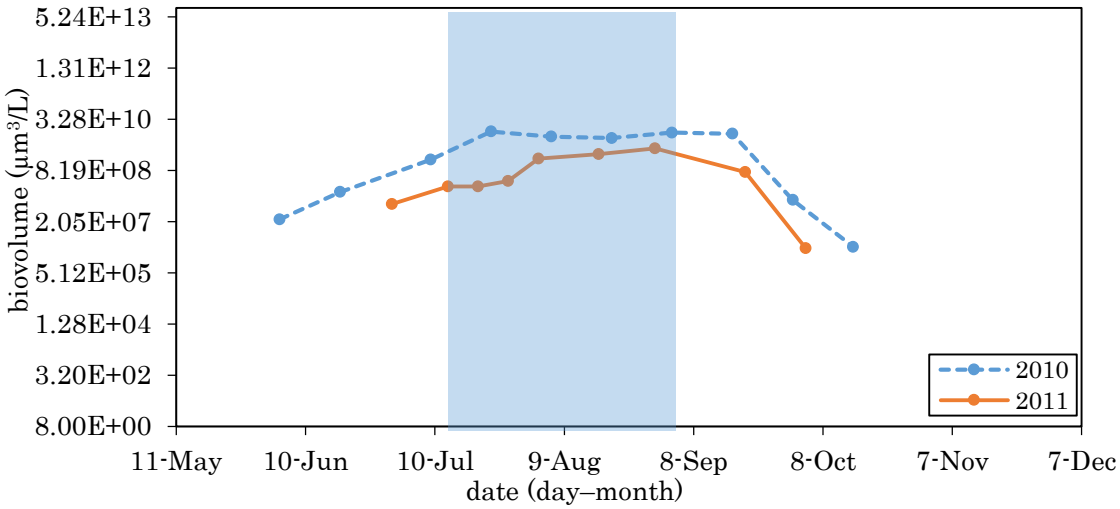

Figure 42. Depth-weighted average biovolume of dinoflagellates at Site A: 2010 with aeration during entire period and 2011 without aeration in shaded area.

Dinoflagellates are among common phytoplankton classes during summer months in temperate lakes. The dinoflagellates are considered to have a slower uptake rate for P, which defines their relatively slow growth rate in comparison to other phytoplankton (Margalef, 1978; Reynolds, 2006). Their ability to grow and dominate in nutrient limited condition during summer stratification has often been related to their ability to migrate vertically throughout water column. This strategy enables them to acquire N and P from nutrient rich bottom layers of water bodies when they become limited on the surface (Liebermann et al., 1994; Whittington et al. 2000).

5.4.5.2. *Effect of artificial aeration on vertical distribution of dinoflagellates*

Results of vertical distribution of dinoflagellates during the period when aeration was in operation show that similarly to diatoms, dinoflagellates were distributed in deeper layers in the reservoir (Figure 42). ANOVA results confirmed no significant differences in biovolume of dinoflagellates among the sampling depths during the aerated period at Site A ($p=0.77$, Table E72). These results suggest that that the mixing dispersed the dinoflagellates deeper in the deeper part of the impoundment. Similarly, no significant differences between sampling depths were confirmed by ANOVA at Site C ($p=0.77$), and Site D ($p=0.89$) (Tables E75 and E76, respectively). Significant differences between sampling depths were observed at Site B ($p=0.02$, Table E73). Tukey's test show that differences occur between the Surface and the Secchi depth ($p=0.02$, Table E74).

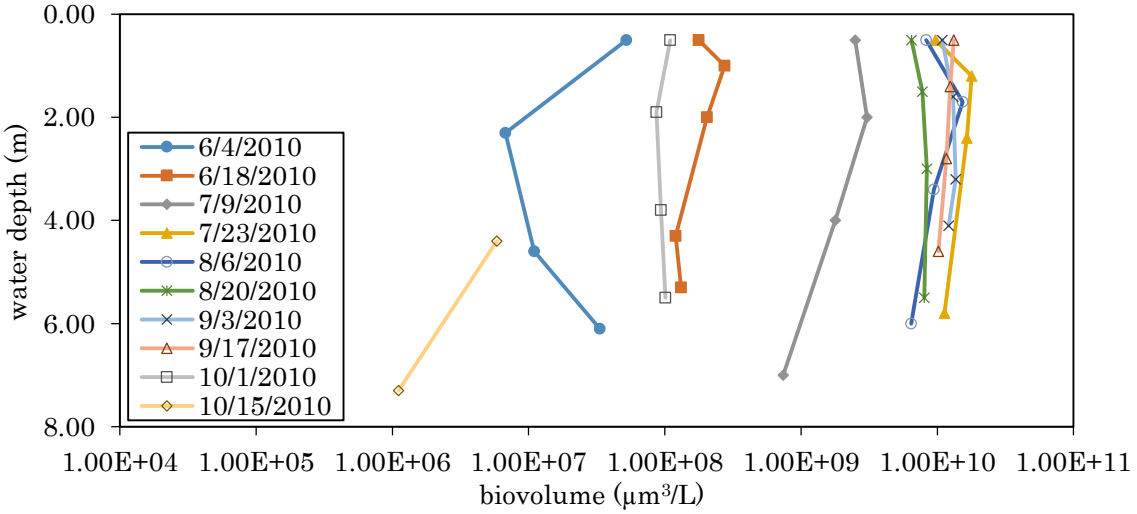

Figure 43. Vertical variation in biovolume of dinoflagellates at Site A (2010) with aeration during entire period

In 2011, however, when the aeration was turned off, dinoflagellates showed a tendency to accumulate at the surface and the Secchi depth layers in the HMD (Figure 44). ANOVA analysis at Site A show a significant difference in dinoflagellates biovolume distribution among sampling depths ($p=0.03$, Table 77). The results from post hoc Tukey's (HSD) test indicate a significant difference between surface and thermocline and 1.5m from the bottom and 0.5m from the bottom ($p=0.03$). However, no significant differences were observed between the surface and Secchi depth ($p=0.70$, Table E78). These results imply that dinoflagellates accumulated in the surface layers of the reservoir when aeration was turned off. The accumulation of dinoflagellates at depths below the surface, where light and nutrients availability were equally sufficient for their growth, has been often observed in other temperate lakes (Klausmeier & Lichman, 2001; Modenutti et al., 2004). No significant differences were found in dinoflagellates biovolume at Sites B, C, or D (Tables E79, E80, and E81, respectively).

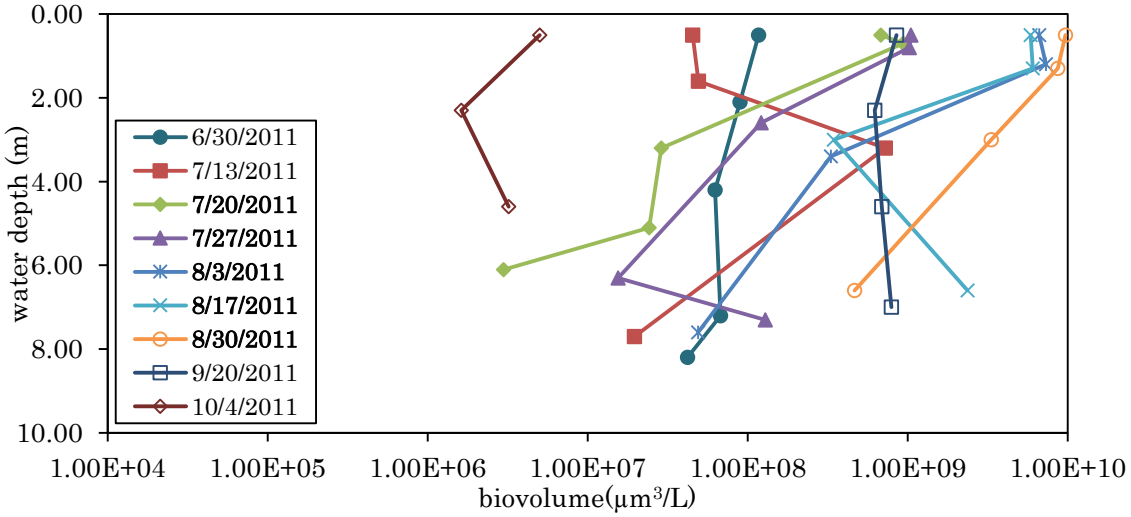

Figure 44. Vertical variation in biovolume of dinoflagellates at Site A (2011) without aeration in bolded dates in the legend.

5.4.5.3. *Effect of artificial aeration on distribution of dinoflagellates between the sites*

The DWA concentrations of dinoflagellates show similar patterns in their variations among the sites. At all sites DWA biovolume increased rapidly in early June and remained relatively higher in the summer months (Table 23). In contrast, in 2011, the dinoflagellates DWA biovolumes (Table 24) at Sites A and B were about 2 times lower than biovolume at Sites C, and D. In addition, the increases of biovolume of dinoflagellates at site A started later in time than the Site B, C, and D. The observed decrease of biovolumes at Sites A and B were coincide with the restricted mixing and observed decrease of nutrient concentrations TDIN and SRP caused by aeration.

Table 23. Dinoflagellates' depth-weighted average biovolume and Standard deviation (STD), 2010

date (mo/day/yr)	dinoflagellates' biovolume (average ± STD), $\mu m^3/L$			
	Site A	Site B	Site C	Site D
6/4/2010	2.41E+07 (1.99E+07)	1.69E+06 (5.04E+06)	3.91E+06 (8.56E+06)	1.50E+07 (2.29E+07)
6/18/2010	1.73E+08 (5.80E+07)	8.12E+06 (1.72E+07)	3.92E+08 (3.68E+08)	5.78E+07 (9.59E+07)
7/9/2010	1.78E+09 (1.02E+09)	5.95E+08 (1.58E+09)	4.53E+09 (3.03E+09)	2.39E+09 (2.33E+09)
7/23/2010	1.36E+10 (3.49E+09)	8.96E+09 (5.30E+09)	1.39E+10 (1.59E+10)	2.75E+10 (8.34E+10)
8/6/2010	9.39E+09 (3.73E+09)	1.16E+10 (5.98E+09)	1.08E+10 (4.24E+09)	1.01E+10 (4.88E+09)
8/20/2010	8.42E+09 (9.06E+08)	6.35E+09 (6.40E+09)	1.02E+10 (8.04E+09)	1.46E+10 (3.40E+09)
9/3/2010	1.25E+10 (1.11E+09)	1.14E+10 (3.57E+09)	9.84E+09 (4.48E+09)	1.19E+10 (5.09E+09)
9/17/2010	1.15E+10 (1.32E+09)	8.49E+09 (6.59E+09)	6.66E+09 (4.56E+09)	1.00E+10 (9.30E+09)
10/1/2010	9.73E+07 (8.93E+06)	4.29E+07 (5.84E+07)	1.88E+09 (2.43E+08)	1.59E+09 (2.76E+09)
10/15/2010	3.30E+06 (2.15E+06)			

Table 24. Dinoflagellates' depth-weighted average biovolume and Standard deviation (STD), 2011

date (mo/day/yr)	dinoflagellates biovolume (average ± STD), $\mu m^3/L$			
	Site A	Site B	Site C	Site D
6/30/2011	7.25E+07 (2.31E+07)	5.76E+07 (1.09E+08)	1.69E+08 (1.35E+08)	1.21E+07 (1.96E+07)
7/13/2011	2.60E+08 (3.65E+08)	9.21E+07 (7.39E+07)	5.80E+07 (8.98E+07)	4.06E+07 (9.29E+07)
7/20/2011	**2.55E+08 (4.24E+08)**	**6.26E+07 (7.09E+07)**	**2.73E+08 (3.67E+08)**	**2.55E+09 (4.79E+09)**
7/27/2011	**3.80E+08 (4.88E+08)**	**4.94E+09 (9.16E+09)**	**7.49E+09 (4.31E+09)**	**1.29E+10 (1.92E+10)**
8/3/2011	**1.93E+09 (3.36E+09)**	**9.98E+09 (7.73E+09)**	**1.18E+10 (7.73E+09)**	**8.98E+09 (7.71E+09)**
8/17/2011	**2.66E+09 (2.42E+09)**	**4.86E+09 (4.72E+09)**	**9.95E+09 (6.40E+09)**	**1.44E+10 (1.47E+10)**
8/30/2011	**4.14E+09 (3.96E+09)**	**3.88E+09 (5.14E+09)**	**2.08E+10 (2.21E+10)**	**1.13E+10 (1.73E+10)**
9/20/2011	7.32E+08 (9.20E+07)	6.27E+09 (2.15E+09)	1.07E+10 (8.04E+09)	1.05E+10 (9.27E+09)
10/4/2011	3.02E+06 (1.46E+06)	1.01E+06 (1.77E+06)	7.45E+07 (1.63E+08)	1.93E+09 (2.94E+09)
10/18/2011		6.48E+06 (1.14E+07)		

Note: bolded values indicate period without aeration

5.4.5.4. *Effect of artificial aeration of Dinophyceae (Dinoflagellate) genera*

Among dinoflagellate, two major genera identified in the HMD were *Peridinium* sp. (Figure 45, a) *and Ceratium* sp. (Figure 45, b). Dinoflagellates were the most abundant genera in the HMD both years (Figure 46, b and 46, b). In 2010, *Peridinium* sp. started to increase rapidly in biovolume (Figure 46, a) in July, followed by relatively higher growth in the warmest months (July-August) when nutrient availability was highest. During most of days, *Peridinium* sp. was the dominant genus comprising 40-90% of the total dinoflagellates biovolume (Figure 46, b). On the other hand, *Ceratium* sp. was the dominant genus at the end of June, after wards its biovolume decreased (Figure 46, b) and remained relatively lower than *Peridinium* sp. (Figure 46, b). Both, *Ceratium* sp and *Peridinium* sp. biovolume were highest the middle of the summer when the nutrient availability was highest.

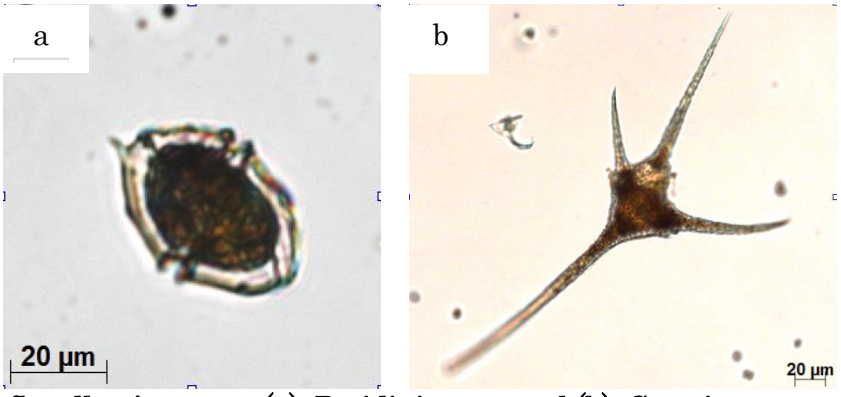

Figure 45. Dinoflagellate's genera (a) *Peridinium* sp. and (b) *Ceratium* sp.

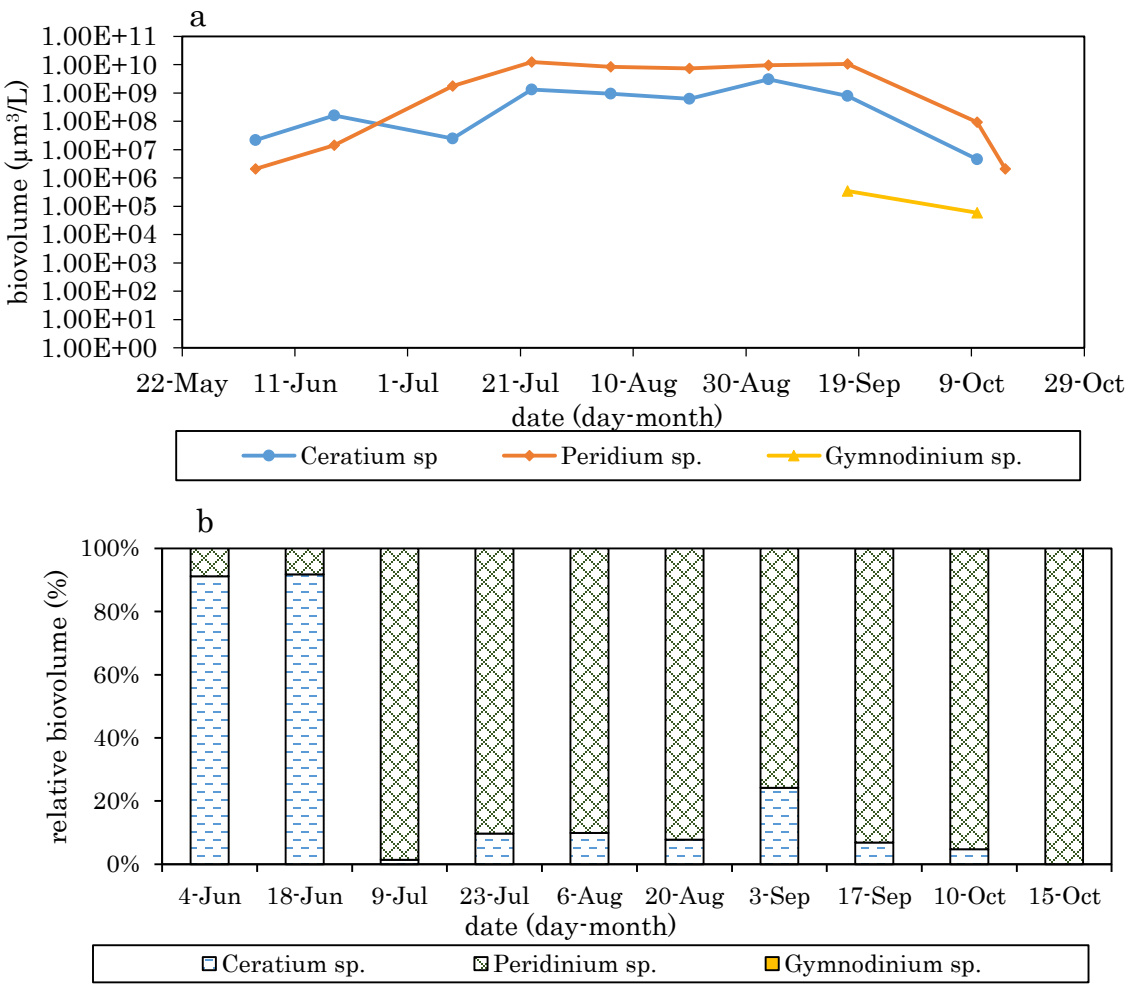

Figure 46. Dinoflagellates' genera at Site A (2010) with artificial aeration in entire period: (a) DWA biovolume and (b) relative biovolume

Similarly, to 2010, in June 2011, when the reservoir was artificially aerated, *Ceratium* sp. increased and was the dominant genera and accounted for about 97% of the total dinoflagellates (Figure 47, a and b). After the aeration was stopped, *Ceartium* sp. biovolume decreased gradually and remined relatively low comprising from 26 to below 1%. In the same period, when aeration was stopped, *Peridinium* sp. increased rapidly about a month later than *Ceartium* sp., showed constant growth in August, and accounted for 70% of the total phytoplankton biovolume (Figure 47, a and b).

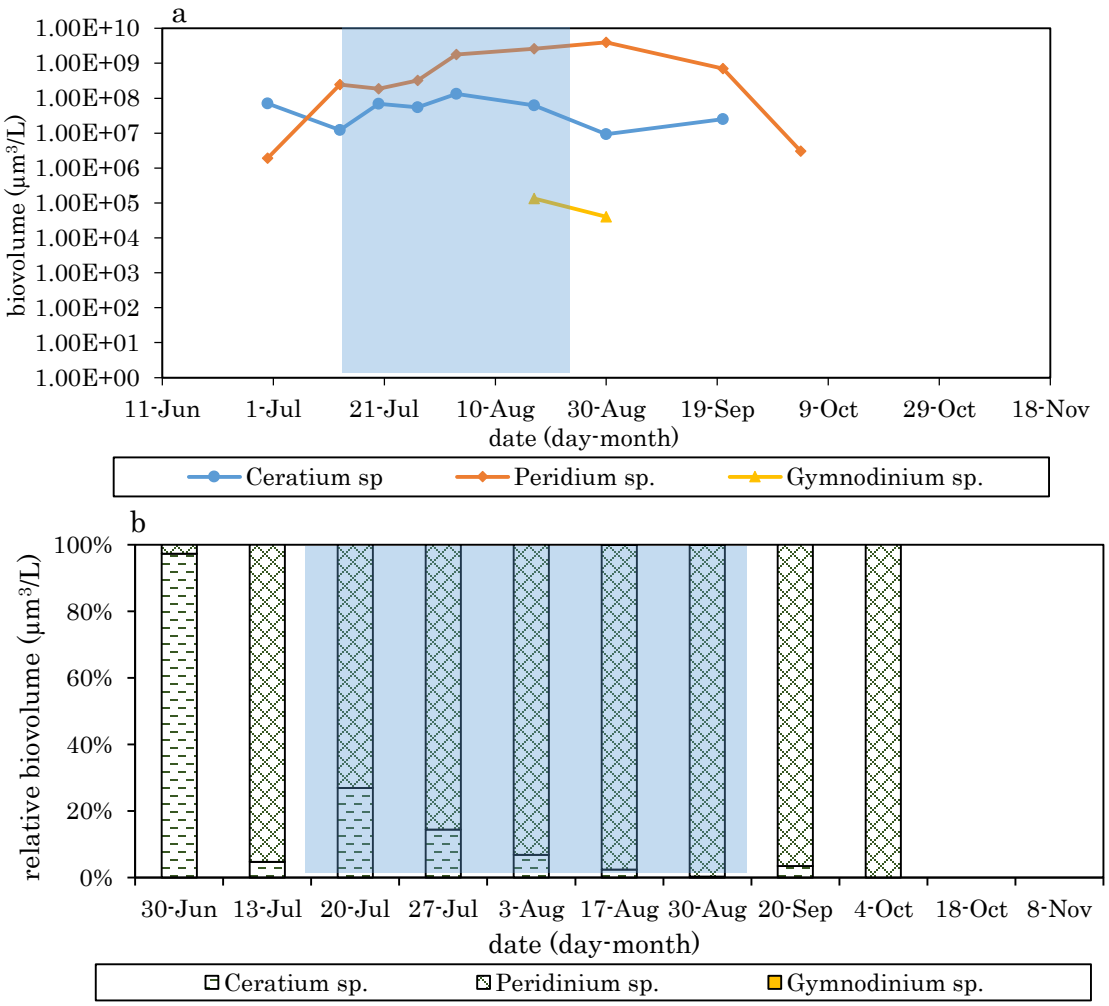

Figure 47. Dinoflagellates' genera at Site A (2011) without aeration in shaded period: (a) DWA biovolume and (b) relative biovolume.

Ceratium sp. and *Peridinium* sp. are described as typically dominant during summer stratification in temperate lakes when N and P become limiting in the epilimnion (Lindstörm, 1992; Reynolds, 2006). Both are able to perform vertical migration between areas of different nutrient concentrations of nutrients and usually are faster than other phytoplankton genera (Taylor, 2007). Moreover, as found by *Ceratium* sp. these migrations are not restricted by stratification (Frempong, 1984). It has been found that the N-limitation could trigger downward migration (Heaney & Eppley, 1981). *Ceratium* sp. and *Peridinium* sp. also can supplement their nutrient requirements through phagocytosis

(Hansen & Calado, 1999; Li et al., 2000; Pérez-Martínez & Sánchez-Castillo, 2002; Clegg et al., 2004). In the HMD, we do not have evidence of phagocytosis of these two species, but the nutrient condition in the lake is likely to support dinoflagellate dominance. Artificial aeration did not change the dominance of dinoflagellates in the summer, but resulted in higher and earlier growth when reservoir was aerated. Increased turbulent mixing has been demonstrated to increase population growth of *Peridinium* sp (Berman et al., 1998), but decrease growth of *Ceratium* sp. (Lindenshmidt & Chorus, 1997). This is just another evidence that mixing, that increases nutrient availability, support the significantly higher growth of dinoflagellates.

5.4.6. Effect of artificial aeration on Chlorophyceae (green algae)

DWA biovolume of green algae in the HMD in 2010 is shown on Figure 48. In 2010, when the reservoir was artificially aerated, the DWA biovolume of green algae showed a seasonal variation of relatively higher biovolume in June, which decreased in the mid-summer before increasing again in fall months. In 2011 (July 13th) the green algae biovolume was about 10 times higher than the biovolume at the same time in 2010 (July 9th). After the artificial aeration was stopped, the biovolume of green algae was still at about the same magnitude higher as in 2010, but gradually decreased in the beginning of August. From end of August to October, the DWA biovolume of green algae in 2011 followed similar distribution for the same period in 2010. Statistical comparison of DWA biovolumes between the period without aeration in 2011 and similar period when the lake was aerated in 2010 show no significant differences (WMW, p=0.12, Table 112).

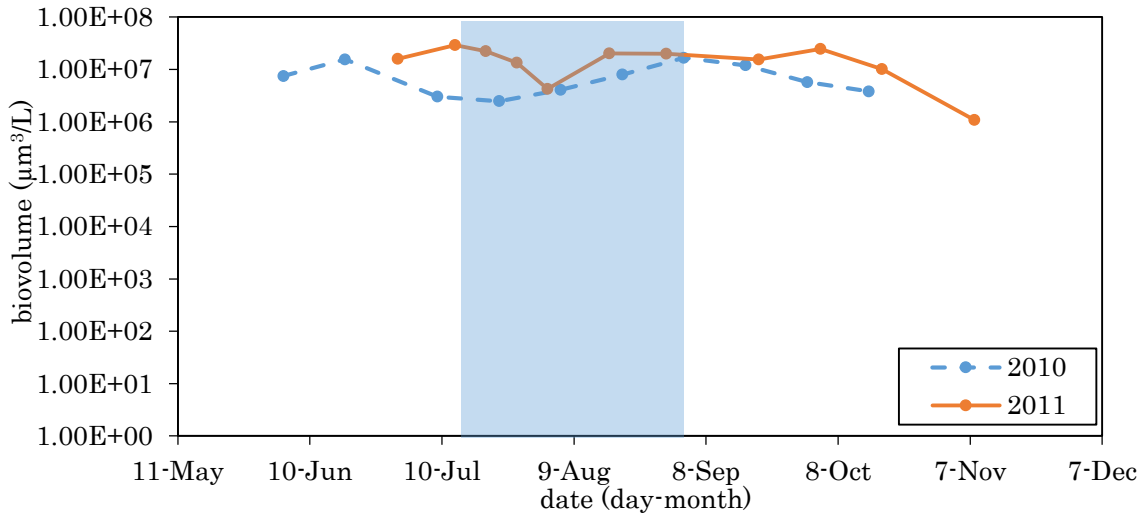

Figure 48. Depth-weighted average biovolume of green algae at Site A: 2010 with aeration during entire period and 2011 without aeration in shaded area.

Studies show that green algae growth is common during the initial phase of summer stratification when the nutrients are still available (Reynolds, 2006; Sommer, 1985). In addition, most of the green algae, similarly to diatoms, require mixing to remain suspended in the water column. An increase of green algae as result of artificial aeration has been reported in many studies (Visser et al., 1996; Lindenshmidt & Chorus, 1997; Becher et al, 2006; Antenucci et al., 2006). However, the results from the HMD show an opposite effect of artificial aeration. Although nutrient availability was higher, due to aeration, green algae remained in relatively lower biovolume in comparison to diatoms and dinoflagellates.

5.4.6.1. *Effect of artificial aeration on vertical distribution of green algae*

Vertical variations in the green algae biovolumes in 2010 show that similarly to diatoms and dinoflagellates, green algae were dispersed deeper in the water column, when the reservoir was aerated (Figure 49). ANOVA results confirmed no significant differences in green algae distribution in water column at Site A ($p=0.35$, Table. 82). No significant differences between water depths were confirmed at Site C ($p=0.94$) or Site D ($p=0.68$)(Tables 85 and 86, respectively). ANOVA results confirmed that significant

difference, however, between the sampling depths were found at Site B ($p<0.01$, Table. 83). Tukey's test show significant differences between the surface and 1.5m from the bottom ($p<0.01$) and surface and Secchi depth ($p=0.01$), as well as 2 × Secchi depth and 1.5m from the bottom ($p=0.02$)(Table. 84).

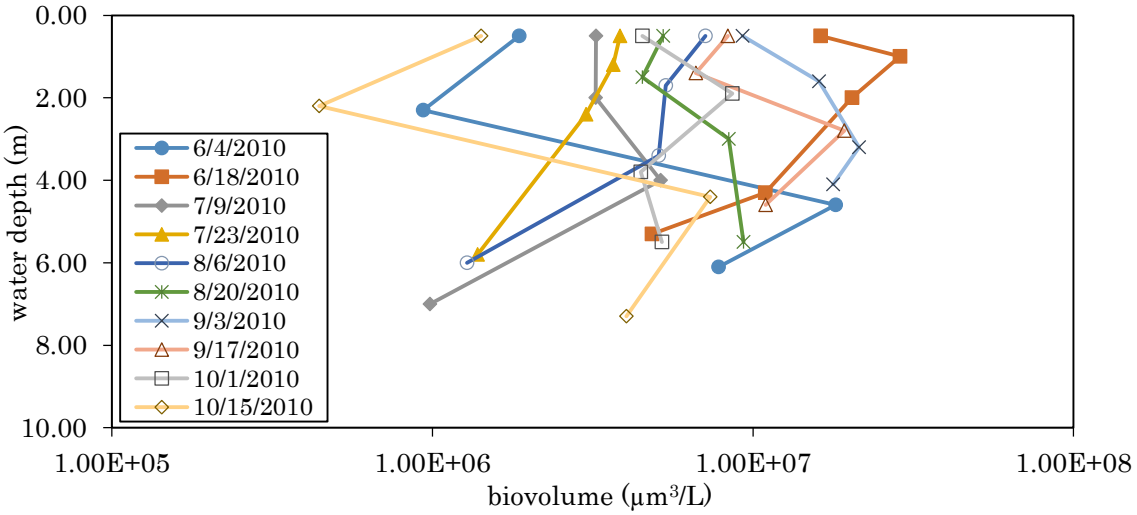

Figure 49. Vertical variations in biovolumeof green algae at Site A (2010) with aeration in entire period

In 2011, when the lake was not aerated, green algae were less evenly distributed (Figure 50). Similar to diatoms, a week after the aeration was turned off, the biovolume of green algae increased at the bottom layers but decreased on the surface indicating settling of green algae in the deeper layers as result of reduced mixing. Over the next weeks, green algae showed a tendency to grow on the surface illuminated layers. Since the p-value of ANOVA analysis is 0.05 we cannot conclusions if significant or no significant difference exists between the depths at Site A ($p=0.05$, Table. 87). However, ANOVA results showed no significant differences between the depths for Sites B ($p=0.83$), C ($p=0.89$), and D ($p=0.33$) (Tables E88, E89, and E90, respectively). Results from statistical analysis indicate that the artificial aeration likely had a little or no effect on green algae vertical distribution.

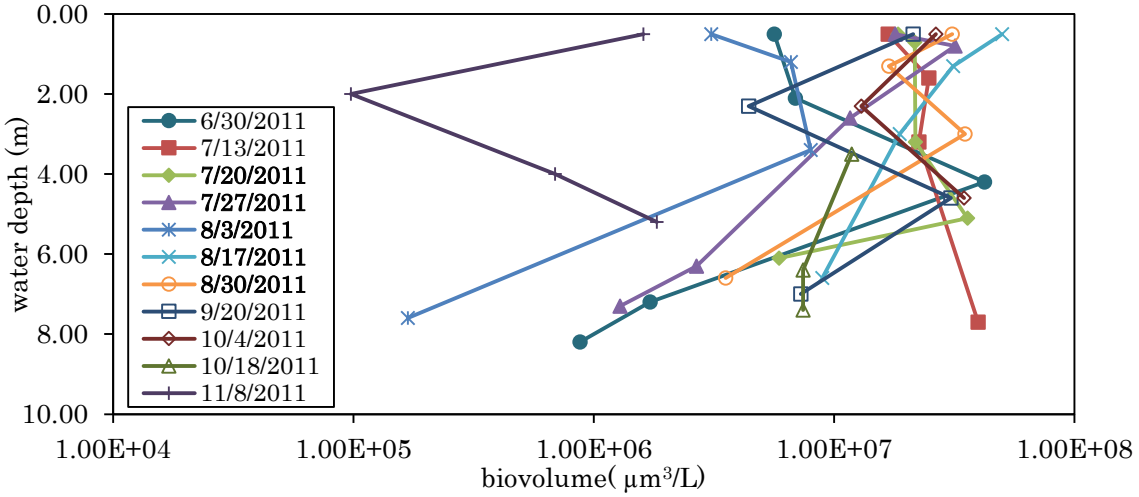

Figure 50. Vertical variation in biovolume of green algae at Site A (2011) without aeration in bolded dates in the legend

5.4.6.2. *Effect of artificial aeration on green algae distribution between the sites*

In 2010, when the lake was aerated, the DWA biovolume of green algae showed similar distribution patterns among sites of decreasing in summer, indicating limited growth in the entire reservoir (Table 25).

Table 25. Green-algae depth-weighted average biovolume and Standard deviation (STD), 2010

Date (mo/day/yr)	Green algae biovolume (average ± STD), $\mu m^3/L$			
	Site A	Site B	Site C	Site D
6/4/2010	7.43E+06 (7.80E+06)	1.12E+07 (2.02E+07)	7.30E+06 (7.36E+06)	5.45E+06 1.45E+07
6/18/2010	1.56E+07 (8.29E+06)	3.53E+07 (2.36E+07)	2.52E+07 (2.29E+07)	2.26E+06 5.00E+06
7/9/2010	3.01E+06 (1.88E+06)	1.13E+07 (6.30E+07)	3.41E+06 (2.25E+06)	8.69E+06 5.70E+06
7/23/2010	2.48E+06 (1.16E+06)	1.04E+07 (1.33E+07)	7.47E+06 (1.69E+07)	4.62E+06 1.04E+07
8/6/2010	4.08E+06 (2.52E+06)	9.00E+06 (4.46E+06)	1.08E+07 (1.16E+07)	8.92E+06 5.21E+06
8/20/2010	7.95E+06 (2.45E+06)	1.15E+07 (2.41E+07)	1.80E+07 (2.11E+07)	1.41E+07 7.15E+06
9/3/2010	1.66E+07 (4.60E+06)	1.16E+07 (7.06E+06)	2.48E+07 1.71E+07	2.65E+07 5.13E+06
9/17/2010	1.19E+07 (5.39E+06)	9.75E+06 (4.74E+06)	1.71E+07 2.75E+07	1.40E+07 8.17E+06
10/1/2010	5.70E+06 (1.90E+06)	1.29E+07 (1.22E+07)	3.91E+06 2.81E+06	5.28E+06 3.07E+06
10/15/2010	3.80E+06 (3.06E+06)	2.32E+07 (6.42E+06)		

In 2011, an increase of green algae DWA biovolume shortly after the aeration was stopped was observed at all sites in the reservoir (Table 26). Higher was the biovolume of green algae at Site B and Site C.

Table 26. Green-algae depth-weighted average biovolume and Standard deviation (STD), 2011

date (mo/day/yr)	Green algae biovolume (average ± STD), μm³/L			
	Site A	Site B	Site C	Site D
6/30/2011	1.59E+07 (2.04E+07)	2.29E+06 (4.41E+06)	1.26E+07 1.79E+07	9.28E+06 2.73E+07
7/13/2011	2.92E+07 (1.00E+07)	2.87E+07 (3.16E+07)	2.55E+07 2.55E+07	3.15E+07 1.71E+07
7/20/2011	**2.23E+07** **(1.03E+07)**	**1.19E+07** **1.17E+07**	**1.15E+07** **7.12E+06**	**1.44E+07** **1.40E+07**
7/27/2011	**1.35E+07** **(1.24E+07)**	**7.67E+06** **1.50E+07**	**1.74E+07** **3.25E+07**	**2.83E+07** **2.26E+07**
8/3/2011	**4.22E+06** **(3.96E+06)**	**1.41E+07** **1.44E+07**	**5.05E+07** **5.44E+07**	**2.50E+07** **3.58E+07**
8/17/2011	**2.01E+07** **(1.45E+07)**	**5.39E+07** **7.08E+07**	**3.63E+07** **5.55E+07**	**3.91E+07** **3.49E+07**
8/30/2011	**1.99E+07** **(1.52E+07)**	**6.00E+07** **7.10E+07**	**2.63E+07** **2.78E+07**	**2.47E+07** **4.83E+07**
9/20/2011	1.53E+07 (1.22E+07)	2.97E+07 1.43E+07	2.39E+07 2.44E+07	2.54E+07 1.71E+07
10/4/2011	2.44E+07 (1.07E+07)	1.53E+07 1.87E+07	7.33E+06 5.93E+06	8.36E+06 2.25E+07
10/18/2011	1.02E+07 (2.39E+06)	3.53E+07 2.41E+07	1.43E+07 1.49E+07	1.21E+07 2.47E+07
11/8/2011	1.08E+06 (8.05E+05)	6.64E+06 9.44E+06	5.07E+06 7.25E+06	1.50E+07 1.67E+07

Note: bolded values indicate period without aeration

5.4.6.3. *Effect of artificial aeration of green algae genera*

Green algae are large and morphologically diverse group of phytoplankton. The basic morphology comprises unicellular, colonial, and filamentous. Many of green algae are flagellate, at least in the gametes stages (John, 2002; Reynolds 2006). Total of 11 genera of green algae were identified in the HMD during 2010 and 2011 (Table 21), some of which are shown in Figure 51.

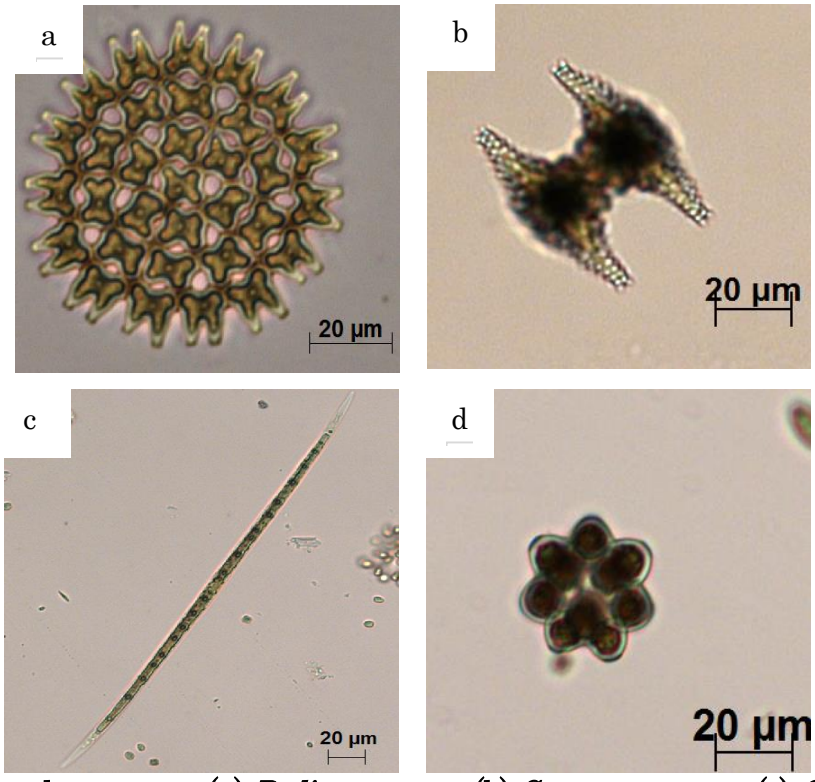

Figure 51. Green algae genera (a) *Pediastrum* sp., (b) *Staurastrum* sp., (c) *Closterium* sp., and (d) *Coelastrum* sp.

Pediastrum sp. and *Staurastrum* sp. DWA increased and were among the dominant genera in June (Figure 52, a). Although in low numbers *Pediastrum* sp. and *Staurastrum* sp. comprised the majority of the green algae in most of days (Figure 52, a and b). Due to the large size of colonies and cells of these genera, together they represented a relatively higher proportion (more than 60%) of total green algae biovolume (Figure 52, b). Both *Pediastrum* sp. and *Staurastrum* sp. rapidly decreased in summer months indicating limiting condition for their growth.

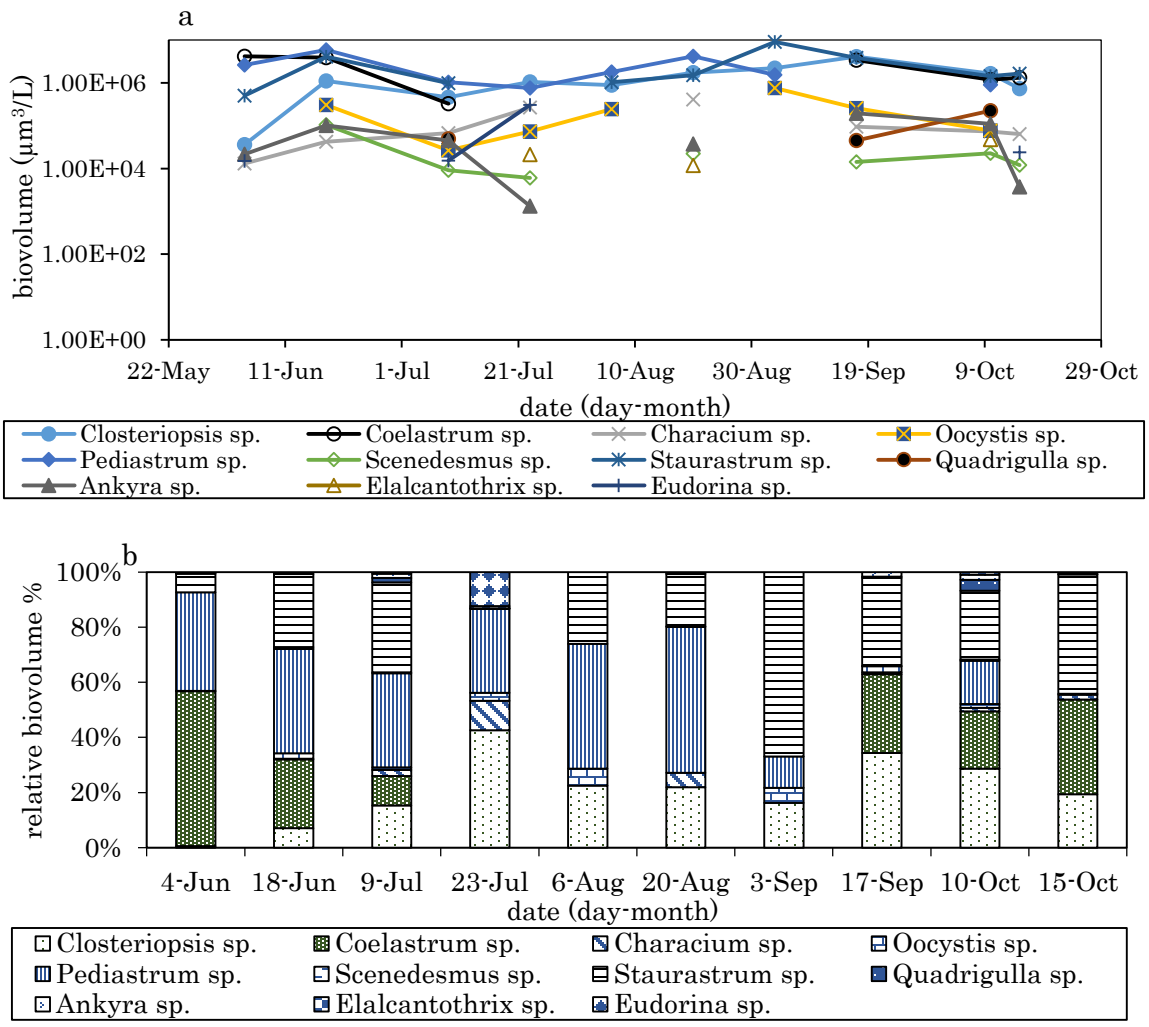

Figure 52. Green algae at Site A (2010) with aeration in entire period: (a) DWA biovolume and (b) relative biovolume.

Closterium sp. DWA increased gradually over the 2010 sampling period indicating slow but not limited growth, when reservoir was aerated, but was less than 30% of the total green algae biovolume (Figure 52, b). *Coelastrum* sp. rapidly decreased in the end of June and was not detected until the middle of September, indicating that the genera become limited. On the other hand, *Oocystis* sp. and *Characium* sp., DWA increased in the middle of summer, but were relatively less than 30% of the total DWA (Figure 52, a and b). *Eudorina sp.* appeared episodically and most of time was below 15% of total green algae DWA (Figure 52, and b). *Pediastrum* sp. and *Coelastrum* sp. usually have higher nutrient

requirements (Reynolds et al, 2002); however, low nitrogen concentrations in the HMD likely resulted in a limited growth of those species.

In 2011, similarly to 2010, *Pediastrum* sp. was present in water column on most days (Figure 53, a) and represented a relatively higher proportion of total DWA biovolume green algae (above 60%) in the HMD (Figure 53, b). After the aeration was turned off, *Pedistrum* sp. DWA remained relatively constant over the next two weeks after which it decreased before increasing again in August, when the reservoir was not mixed. This indicates that the aeration did not change its overall distribution in the HMD. In contrast to 2010, *Staurastrum* sp. DWA biovolume decreased after the aeration was stopped (Figure 53, a). A similar decrease in biovolume during the non-aerated period has been observed in *Closterium* sp., *Ankyra* sp, *Coelastrum* sp., and *Characium* sp. The decrease of most of the green algae genera concurrent with decrease of nutrient availability in the reservoir suggest that green algae become limited.

The prolonged presence of *Pediastrum* sp. in the water column suggest that sudden turn off of the mixing did not result in immediate decrease of *Pediastrum* sp. colonies. *Pediastrum* sp. has a relatively slower sinking velocity than *Staurastrum* sp, and other phytoplankton genera (Padisák et al., 2003). In addition, *Pediastrum* sp., as well as *Scenedesmus* sp. have ability to assimilating dissolved organic nitrogen, which might explain their relatively higher growth (Berman & Chava, 1999; Mandal & Mallic, 2010). In contrast, colonial flagellate green algae *Pandorina* sp. and *Eudorina* sp. (Figure 54, a and b) increased after the onset of developing of stratification in the HMD (Figure 53, a). The increase of flagellate green algae growth was observed after developing of stratification and successful during periods of nutrients depletion has been attributed to their ability to migrate to nutrient rich waters in the hypolimnion. (Happey-Wood, 1976; Reynolds, 2006).

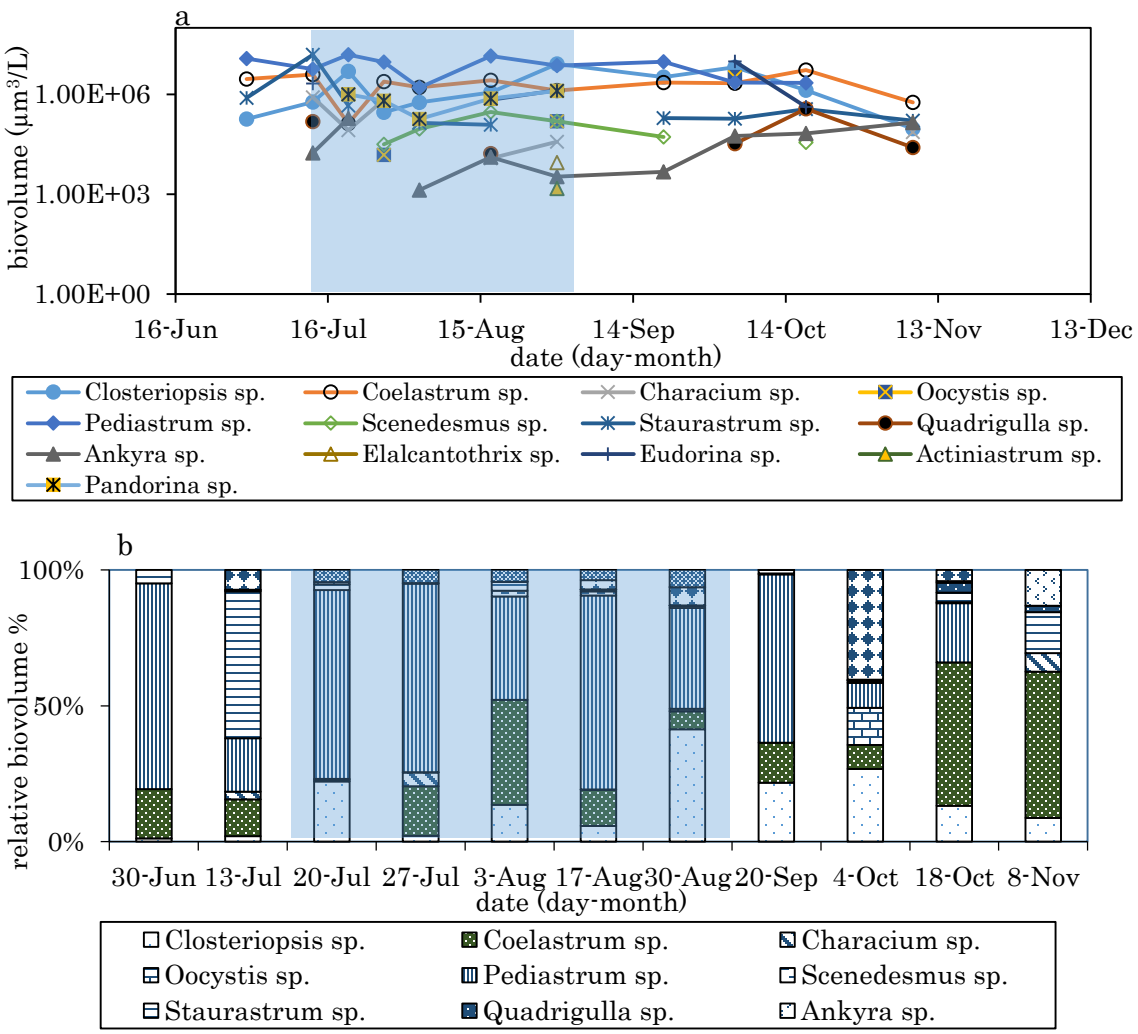

Figure 53. Green algae at Site A (2011) without aeration in shaded area (a) DWA biovolume and (b) relative biovolume.

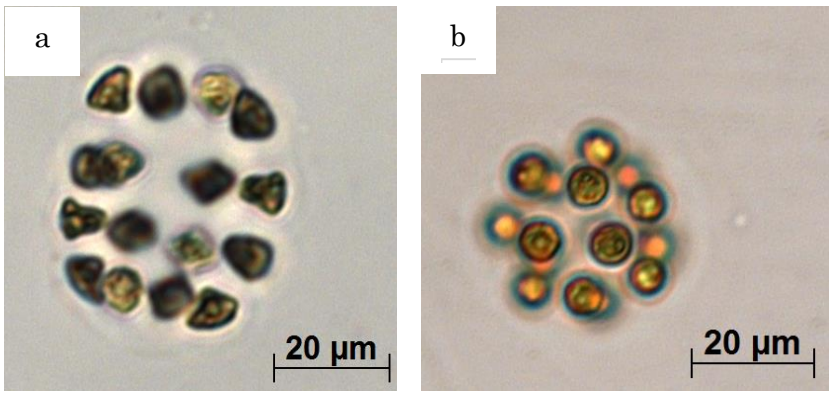

Figure 54.Green algae genera (a) *Pandorina* sp. and (b) *Eudorina* sp.

5.4.7. Effect of artificial aeration on Cyanobacteria (blue-green algae)

Variations in DWA biovolume of Cyanobacteria in the HMD in 2010 and 2011 at Site A are shown in Figure 55. In 2010, when the reservoir was artificially aerated, Cyanobacteria increased from June to July and peaked at the end of July-August when the water was warmest and nutrient availability was highest. Cyanobacterial DWA biovolume decreased toward the fall months. In June 2011, however, when aeration was in operation, Cyanobacterial DWA biovolume increased rapidly from June to the beginning of July. On July 13th, a higher density of Cyanobacterial genera and higher biovolume indicated that a bloom had occurred (Figure 55). After the aeration was stopped on July 13th, the DWA biovolume of Cyanobacteria continued to increase and peaked after a week, which indicated that although the nutrients were less available, Cyanobacteria continued to grow. However, after two weeks the Cyanobacterial population collapsed and remained relatively low until the end of the stratified period. The collapse of Cyanobacteria was coincident with the decrease of nutrients on the surface layers. When aeration was resumed, Cyanobacteria showed a slight increase, but decreased again in early October (Figure 55).

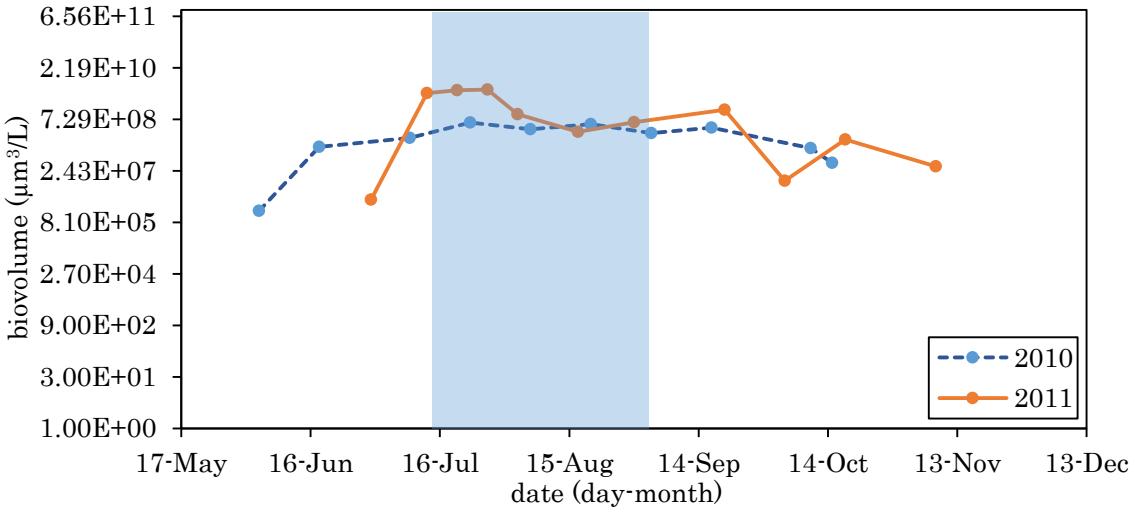

Figure 55. Depth-weighted average biovolume of Cyanobacteria at Site A: 2010, with aeration in entire period and 2011, without aeration in shaded area.

Cyanobacteria are among the phytoplankton classes typical for temperate lakes in summer months. Increase of Cyanobacteria growth and frequent blooms has been associated with accelerated eutrophication of the water bodies (Oliver & Ganf, 2000). Cyanobacterial excessive growth is also often explained and related to the low N:P ratio in eutrophic lakes and reservoirs because of ability of some species, such as *Anabaena* sp. and *Aphanizomenon* sp., to fix nitrogen from the atmosphere (Smith, 1985, Levine & Schindler 1999). The studies investigating the effect of artificial mixing on Cyanobacterial growth showed mixed and inconclusive results on the effect of artificial destratification on their growth. Cyanobacteria in the HMD persist both years when aeration worked and their densities were about 10 times higher in 2011. Nevertheless, the problem with the higher Cyanobacterial growth was not solved. The results from the WMW test show no significant differences ($p=0.11$, Table E113) in DWA biovolume of Cyanobacteria between the periods without stratification in 2011 and the same period with artificial aeration in 2010.

5.4.7.1. *Effect of artificial aeration on vertical distribution of Cyanobacteria*

Results of vertical distribution of Cyanobacteria at Site A during aeration show that the Cyanobacteria, similarly to other phytoplankton, were dispersed in deeper layers in the reservoir (Figure 56). ANOVA results confirmed no significant differences in Cyanobacterial distribution in the water column when the reservoir was artificially aerated ($p=0.97$, Table E91). Similar to Site A, no significant differences between sampling depths at Sites B ($p=0.57$), C ($p=0.57$), or D ($p=0.91$) (Tables E92, E93, and E94, respecytively), indicating that the Cyanobacteria were evenly distributed over the depths in each site in the reservoir. Similar uniform distribution of Cyanobacteria as result of aeration was also found by Visser et al. (1996) and Heo and Kim (2004).

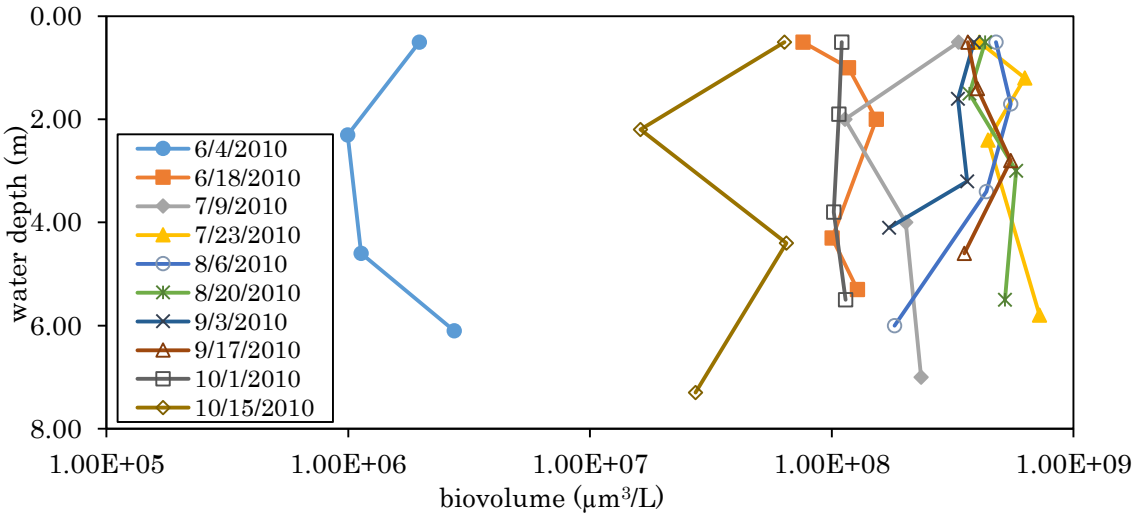

Figure 56. Vertical variations in biovolume of Cyanobacteria at Site A (2010) with aeration in entire period.

In 2011, for two weeks after the aeration was turned off, Cyanobacterial biovolume increased significantly on the surface but decreased in bottom layers (Figure 57). This accumulation on the surface layers in the impoundment is also an evidence of the ability of Cyanobacterial genera to regulate their buoyancy, which is an ecologically important mechanism enabling them to adjust vertical position in the water column usually under calm (stable, stratified) condition (Walsby, 1987). For the whole period ANOVA analysis showed no significant differences among the sampling depths ($p=0.07$) (Table E95). Based on statistical analysis we cannot conclude that the accumulation of Cyanobacteria occur on the surface in the HMD; however, similar accumulations of *Aphanizomenon* sp. on the surface layers after mixing events were observed by Stal and Walsby (2000). The biovolume increase on the surface was not only a result of accumulation of Cyanobacteria but also a result of continuous growth, which was evident from an increase in total Cyanobacterial biovolume (Figure 55). The accumulation of Cyanobacteria on the surface was coincident with a decrease of nutrient availability on the surface, which caused the consequent decline of the population.

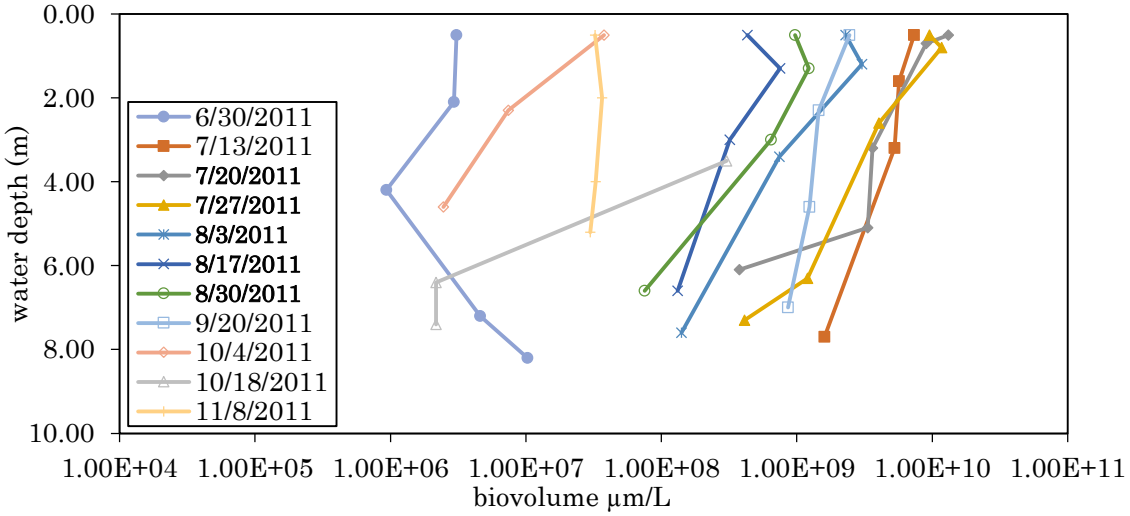

Figure 57. Vertical variation in biovolume of Cyanobacteria at Site A (2011) without aeration in bolded dates in the legend

5.4.7.2. *Effect of artificial aeration on distribution of Cyanobacteria between the sites*

In 2010, DWA biovolumes from the sampling sites showed a similar distribution of Cyanobacteria with a maximum growth in the end of July (Table 27).

Table 27. Cyanobacterial depth-weighted average biovolume and Standard deviation (STD), 2010.

date (mo/day/yr)	Cyanobacterial biovolume (average ± STD), µm³/L			
	Site A	Site B	Site C	Site D
6/4/2010	1.72E+06 (8.57E+05)	1.06E+08 (3.26E+08)	1.22E+07 (1.11E+07)	1.69E+06 (1.82E+06)
6/18/2010	1.18E+08 (2.91E+07)	2.72E+08 (7.23E+08)	7.97E+08 (1.14E+09)	3.68E+07 (8.17E+07)
7/9/2010	2.15E+08 (7.68E+07)	1.39E+08 (3.02E+08)	1.67E+08 (7.14E+07)	2.45E+08 (2.91E+08)
7/23/2010	5.86E+08 (1.58E+08)	6.55E+08 (6.55E+08)	1.12E+09 (2.40E+09)	8.56E+08 (2.49E+09)
8/6/2010	3.74E+08 (1.71E+08)	2.95E+08 (2.76E+08)	2.08E+08 (1.10E+08)	4.39E+08 (1.94E+08)
8/20/2010	5.24E+08 (9.93E+07)	1.82E+08 (1.21E+08)	3.64E+08 (3.67E+08)	5.12E+08 (4.77E+08)
9/3/2010	2.94E+08 (1.04E+08)	5.60E+08 (3.85E+08)	3.99E+08 (2.64E+08)	3.30E+08 (1.56E+08)
9/17/2010	4.16E+08 (9.42E+07)	2.80E+08 (4.60E+08)	1.76E+08 (2.45E+08)	4.62E+08 (3.98E+08)
10/1/2010	1.09E+08 (5.50E+06)	5.85E+07 (9.24E+07)	3.32E+08 (2.58E+08)	4.05E+07 (2.88E+07)
10/15/2010	4.13E+07 (2.43E+07)	1.01E+07 (3.03E+07)		

In 2011, a rapid and higher increase of DWA biovolumes of Cyanobacteria were observed at all sites in the reservoir when aeration was in operation (Table 28). Two weeks after aeration was stopped Cyanobacteria bloom collapsed in the whole reservoir.

Table 28. Cyanobacterial depth-weighted average biovolume and Standard deviation (STD), 2010.

date (mo/day/yr)	Cyanobacteria biovolume (average ± STD), µm3/L			
	Site A	Site B	Site C	Site D
6/30/2011	3.63E+06 (3.12E+06)	3.22E+07 (7.19E+07)	4.20E+07 (8.84E+07)	8.20E+06 (7.58E+06)
7/13/2011	4.07E+09 (2.39E+09)	4.34E+09 3.72E+09	4.70E+09 (2.48E+09)	5.46E+09 (4.27E+09)
7/20/2011	4.95E+09 (4.13E+09)	7.84E+09 7.84E+09	7.22E+09 (3.26E+09)	9.92E+09 (1.19E+10)
7/27/2011	5.15E+09 (4.73E+09)	6.95E+09 7.41E+09	7.49E+09 (4.31E+09)	1.28E+10 (9.91E+09)
8/3/2011	1.01E+09 (1.18E+09)	2.35E+09 1.69E+09	2.26E+09 (2.78E+09)	5.94E+09 (5.27E+09
8/17/2011	3.21E+08 (2.36E+08)	2.09E+09 2.22E+09)	1.25E+09 (1.89E+09)	1.43E+09 2.74E+09
8/30/2011	6.05E+08 (4.92E+08)	7.25E+08 9.45E+08	4.30E+09 (7.79E+09)	4.22E+09 6.45E+09
9/20/2011	1.37E+09 (5.92E+08)	1.64E+09 6.99E+08	2.06E+09 (1.21E+09)	2.26E+09 2.66E+09
10/4/2011	1.27E+07 1.57E+07	4.37E+07 8.59E+07	1.23E+07 (2.59E+07	3.26E+07 (3.33E+07)
10/18/2011	1.90E+08 1.63E+08	1.47E+08 1.07E+08	7.99E+07 (5.86E+07)	6.15E+07 (1.69E+08)
11/8/2011	3.27E+07 2.86E+06	7.58E+07 1.48E+08	1.03E+07 (8.15E+06)	3.10E+07 (4.33E+07)

Note: bolded values indicate period without aeration

5.4.7.3. *Effect of artificial aeration of Cyanobacteria genera*

A total number of six genera of class Cyanobacteria were identified in the HMD during 2010 and 2011. Cyanobacterial genera identified in the HMD have two categories of cell organization: colonial (*Microcystis* sp and *Gomphosphaeria* sp.) and filamentous (*Aphanizomenon* sp., *Anabaena* sp., *Lyngbya* sp., and *Oscillatoria* sp.). Among them *Aphanizomenon* sp. and *Anabaena* sp. (Figure 58, a, b, c and d) have an ability to fix N_2- from the atmosphere, which makes them competitive in the N-limited condition.

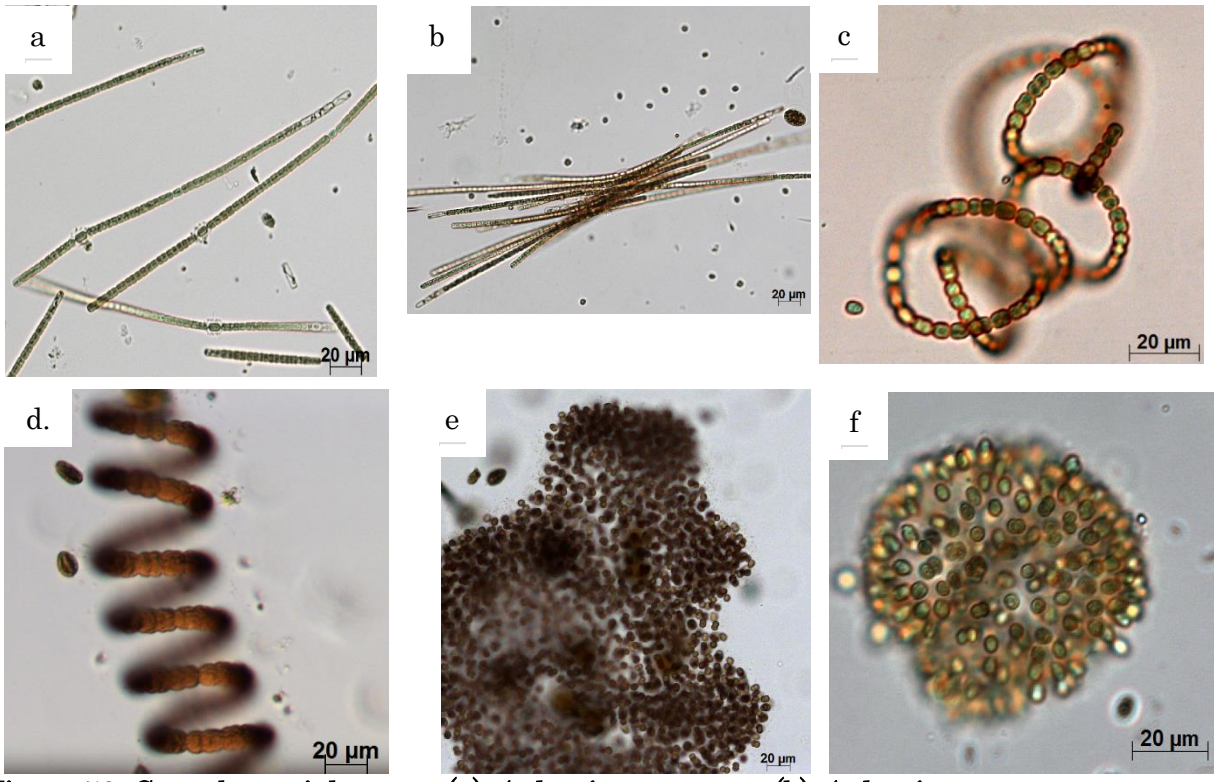

Figure 58. Cyanobacterial genera (a) *Aphanizomenon* sp., (b) *Aphanizomenon* sp. aggregate, (c) *Anabaena* sp. (d)*Anabaena* sp.(e) *Microcystis* sp. and (f) *Gomphosphaeria* sp.

In 2010, N_2-fixing *Anabaena* sp. were present in the water column during the entire season (Figure 59, a). In the beginning of June *Anabaena* sp. was the only Cyanobacterial genus in the HMD, while in July to September, *Anabaena* sp. co-dominated with another N_2-fixing Cyanobacteria: *Aphanizomenon* sp. (Figure 59, b). *Microcystis* sp., non-N_2 fixing Cyanobacteria, DWA biovolume also increased from July until the end of August, after which it decreased toward the fall months (Figure 59, a).Both N_2-fixing and non-N_2-fixing Cyanobacteria species increased in DWA biovolume when the nutrient availability in the reservoir was higher due to aeration. Cyanobacteria have half-saturation constant (Ks) for N ranging from zero to 0.03 mg/L, which is relatively lower than Ks in comparison with diatoms (Tilman et al., 1982), green algae (Sommer. 1986, Shafic, 1991, Spijkerman & Coesel, 1996), dinoflagellates (Berman & Dumbinsky, 1985), and bacterioplankton (Ducobu

et al., 1998) (Table 1, CHAPTER2). Depth-weighted average TDIN concentrations in the HMD ranged between 0.1-0.2 mg/L during 2010 (Table 10), which was relatively low for the phytoplankton growth. In addition, the calculated N:P ratio in the HMD was below 2 both years, which indicates a strong nitrogen limitation. Biovolume of the rest of Cyanobacteria genera, *Gomphosphaeria* sp.(Figure 58, f), *Oscillatoria* sp., and *Lyngbya* sp., remained relatively low (below 30% of the total phytoplankton biovolume) during the entire sampling period (Figure 58, a and b).

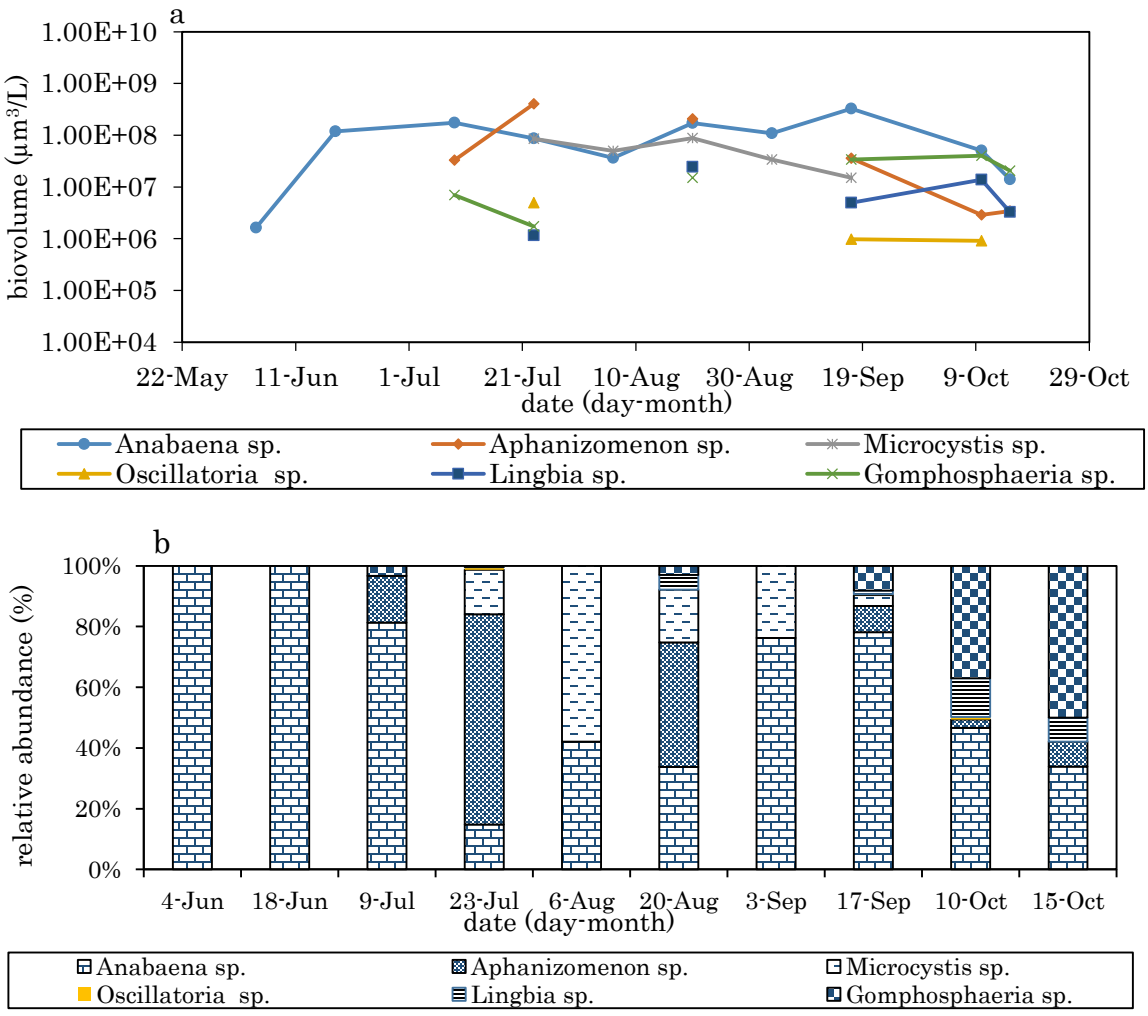

Figure 59. Cyanobacterial genera at Site A (2010) with artificial aeration in entire period: (a) DWA biovolume and (b) relative biovolume.

In the beginning of 2011, when artificial destratification was in operation both *Anabaena* sp. and *Aphanizomenon* sp. DWA biovolume increased rapidly (Figure 60, a). *Anabaena* sp. was a dominant genus in June (60%), while in the beginning of July it was replaced by *Aphanizomenon* sp, which accounted for 85% of the total Cyanobacteria genera (Figure 60, b). When the destratification was turned off, *Aphanizomenon* sp. continued to increase in biovolume (Figure 60, a) and to be a dominant cyanobacterial genus (Figure 60, b). Two weeks after the aeration was stopped, *Aphanizomenon* sp population decreased rapidly, indicating that the population collapsed. Similar to *Aphanizomenon* sp., *Anabaena* sp. and *Microcystis* sp. decreased with decreasing of nutrient availability on the surface in the reservoir. Conversely, although the nutrient availability was low, the biovolume *Gomphosphaeria* sp. increased in the mid-summer when the reservoir was still stratified.

The observed collapse of Cyanobacterial population shortly after stopping aeration coincided with decreased nutrient availability in the surface layers in the reservoir. Although good competitors for nitrogen, based on the results of kinetic studies summarized in Table 1, CHAPTER 2, Cyanobacteria are not good competitors for P (Smith, 1985). For example, *Aphanizomenon* sp. was found to have a higher half-saturation constant for P in comparison with another N_2-fixing genus, *Anabaena* sp. (De Nobel et al., 1997), which makes *Aphanizomenon* less competitive when P is limited. Therefore, it seems that the prolonged P limitation in the HMD resulted in decreased growth and observed collapse of the Cyanobacterial population. On the other hand, biovolumes of *Microcystis sp., Oscillatoria* sp. *Lyngbya* sp*., and Gomphosphaeria* sp., reminded relatively low (Figure 60, b). These genera do not have ability to fix N, and nitrogen limitation in the HMD appears to be the major factor explaining their low biovolumes. More about effect of aeration on Cyanobacteria will be discussed in CHAPTER 6.

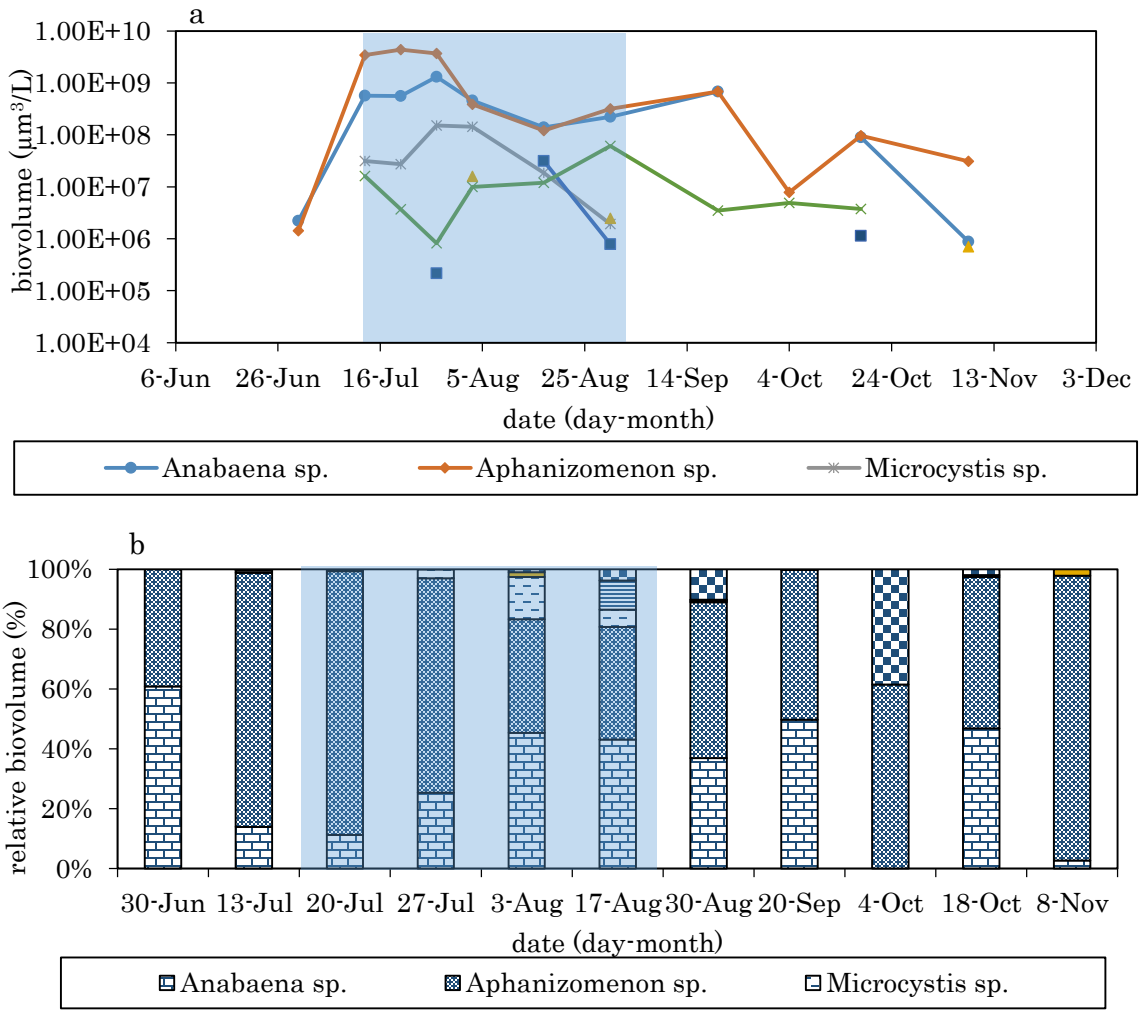

Figure 60. Cyanobacterial genera at Site A (2011) with no artificial aeration in shaded area: (a) DWA biovolume and (b) relative biovolume.

5.4.8. Effect of artificial aeration on Cryptophyceae

Variations in DWA biovolume of Cryptophyceae in the HMD in 2010 and 2011 at Site A are shown in Figure 61. In 2010, when the reservoir was artificially aerated, the DWA biovolume of Cryptophyceae increased in June, followed by a decrease in summer months before increasing again in fall months. In 2011, from June to the beginning of August, Cryptophyceae DWA remained lower than the DWA biovolume in 2010. At the end of the stratified period, the depth-weighted averaged biovolume of Cryptophyceae started to increase and continued to increase after destratification (Figure 61).

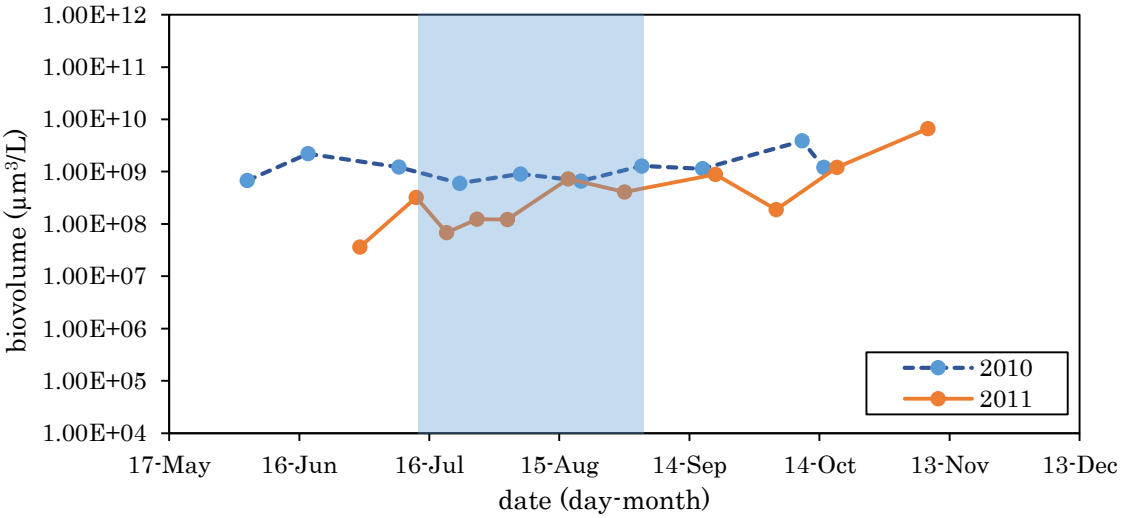

Figure 61. Depth-weighted average biovolume of Cryptophyceae during the sampling seasons: 2010 with aeration during entire season and 2011 without aeration in shaded area.

The results from the WMW test show no significant differences (p=0.07, Table E114) in DWA biovolume of Cryptophyceae between the periods without stratification in 2011 and the same period, with artificial destratification in 2010. Several studies demonstrated an increase in the Cryptophyceae as a result of artificial aeration (Lindenshmidt & Chorus, 1997, 1998), but that was not the case in the HMD.

Cryptophyceae (Figure 62) are common class phytoplankton found throughout the year in temperate lakes (Sommer, 1985). Due to their rapid growth, motility, and ability to supplement their nutrient uptake by phagotrophy, Cryptophyceae are associated with higher tolerance to environmental conditions (Reynolds, 1980, 2002). A population of Cryptophyceae commonly has been found to increase immediately after the decline of other previously dominant phytoplankton genera (Sommer, 1985).

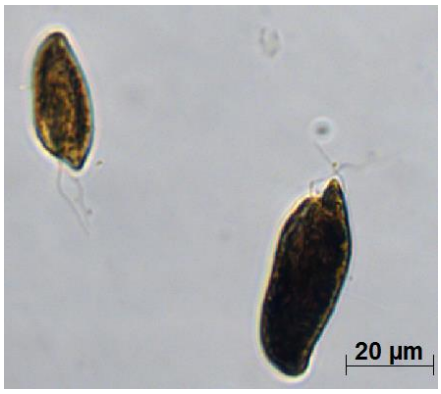

Figure 62. *Cryptophyceae* sp

5.4.8.1. *Effect of artificial destratification on vertical distribution of Cryptophyceae*

Results of vertical distribution of Cryptophyceae during the period when destratification was in operation in 2010 show that the Cryptophyceae, similar to other phytoplankton, were dispersed in deeper layers in the reservoir (Figure 63). ANOVA results show that there were no significant differences between sampling depths of Cryptophyceae biovolume at Site A when the reservoir was artificially aerated (p=0.69, Table E99). No significant differences within depths were found at Sites B (p=0.53), C (p=0.56), or D (p=0.49) (Tables E100, E101, and E102, respectively).

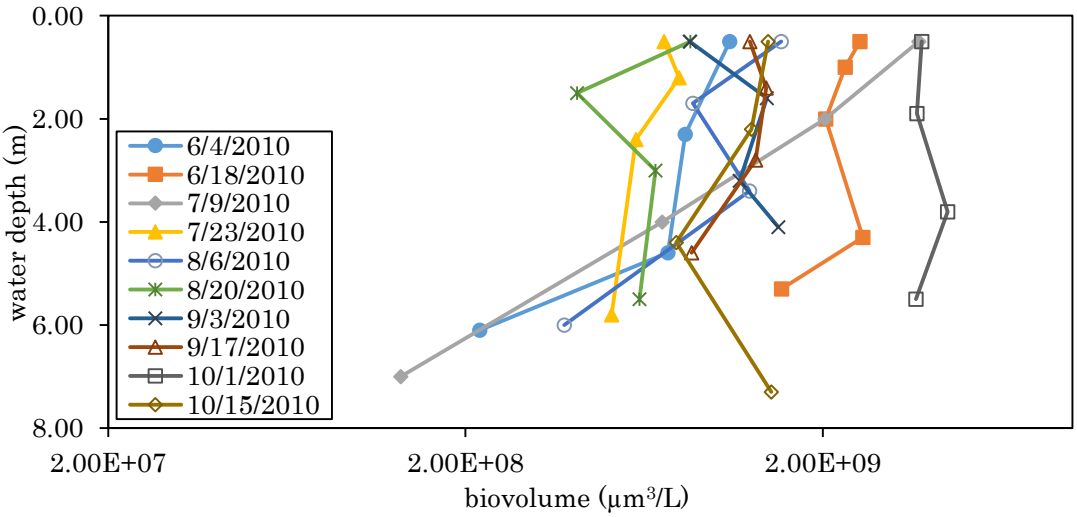

Figure 63.Vertical variations in biovolume of Cryptophyceae (2010) with aeration during entire period.

Reduced mixing in 2011, when aeration was stopped did not changed vertical distribution of Cryptophyceae distribution. The data show that they were still distributed deeper in the water column (Figure 64) and no significant differences in biovolume distribution were found at Sites A (p=0.27), B (p=0.82), C (p=0.95), or D (p=0.59) (Tables E103, E104, E105, and E106, respectively). Thereafter, the artificial aeration did not change significantly the vertical distribution of Cryptophyceae in the HMD.

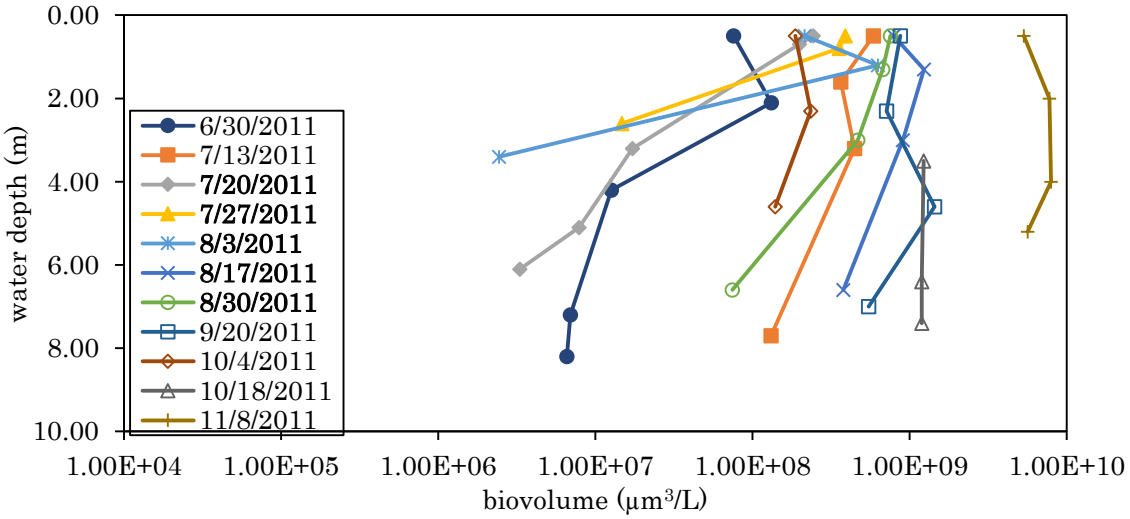

Figure 64. Vertical variations in biovolume of Cryptophyceae (2011) with no aeration in bolded dates in the legend

5.4.8.2. *Effect of artificial aeration on distribution of Cryptophyceae between the sites*

In 2010 the DWA (Table 39) showed a similar distribution of Cryptophyceae among the sampling sites. In the HMD, in 2011, a rapid and higher growth of Cryptophyceae was observed at all sites in the reservoir (Table 30).

Table 29. Cryptophyceae depth-weighted average biovolume and Standard deviation (STD), 2010

date (mo/day/yr)	Cryptophyceae biovolume (average ± STD), $\mu m^3/L$			
	Site A	Site B	Site C	Site D
6/4/2010	6.74E+08 (3.68E+08)	1.43E+08 (2.44E+08	7.84E+08 (9.85E+08)	1.40E+09 (1.53E+09)
6/18/2010	2.21E+09 (4.25E+08)	2.50E+09 (1.76E+10)	1.56E+09 (1.34E+09)	3.46E+07 (6.67E+07)
7/9/2010	1.22E+09 (1.43E+09)	1.84E+09 (3.27E+09)	2.86E+09 (1.91E+09)	2.55E+09 (2.83E+09)
7/23/2010	6.01E+08 (1.14E+08)	4.80E+08 (4.04E+08)	1.01E+09 (2.66E+09)	1.44E+09 (4.41E+09)
8/6/2010	9.04E+08 (5.06E+08)	9.76E+08 (6.50E+08)	1.12E+09 (8.24E+08)	1.04E+09 (3.90E+08)
8/20/2010	6.60E+08 (1.65E+08)	7.63E+08 (6.96E+08)	2.40E+09 (1.86E+09)	1.87E+09 (5.72E+08)
9/3/2010	1.28E+09 (2.78E+08)	1.30E+09 (7.83E+08)	1.31E+09 (5.62E+08)	1.39E+09 (4.14E+08)
9/17/2010	1.14E+09 (2.61E+08)	1.40E+09 (1.21E+09)	1.73E+09 (1.89E+09)	1.47E+09 (1.54E+09)
10/1/2010	3.89E+09 (4.04E+08)	2.77E+09 (4.25E+09)	5.43E+09 (1.09E+09)	3.08E+09 (4.62E+09)
10/15/2010	1.20E+09 (3.22E+08)	1.78E+09 (7.46E+09)		

Table 30. Cryptophyceae depth-weighted average biovolume and Standard deviation (STD), 2011

date (mo/day/yr)	Cryptophyceae biovolume (average ± STD), $\mu m^3/L$			
	Site A	Site B	Site C	Site D
6/30/2011	3.64E+07 5.16E+07	3.96E+08 7.63E+08	9.03E+08 8.63E+08	6.54E+08 8.56E+08
7/13/2011	3.23E+08 1.88E+08	1.14E+08 1.48E+08	2.07E+09 1.92E+09	1.26E+09 7.24E+08
7/20/2011	**6.80E+07** **1.03E+08**	**8.61E+08** **1.63E+09**	**5.73E+08** **6.32E+08**	**4.05E+08** **4.70E+08**
7/27/2011	**1.23E+08** **1.81E+08**	**2.70E+08** **6.02E+08**	**7.31E+07** **4.07E+07**	**5.07E+07** **6.40E+07**
8/3/2011	**1.21E+08** **2.43E+08**	**9.21E+09** **6.91E+08**	**1.97E+09** **3.84E+09**	**1.18E+09** **1.13E+09**
8/17/2011	**7.28E+08** **3.54E+08**	**2.35E+08** **2.61E+08**	**8.91E+08** **6.91E+08**	**1.38E+09** **9.03E+08**
8/30/2011	**4.06E+08** **2.91E+08**	**5.45E+08** **5.64E+08**	**9.48E+08** **1.21E+09**	**1.06E+09** **1.88E+09**
9/20/2011	8.89E+08 4.02E+08	1.67E+09 6.76E+08	9.62E+08 1.45E+09	1.41E+09 1.36E+09
10/4/2011	1.88E+08 4.65E+07	2.65E+08 3.36E+08	5.24E+08 3.46E+08	4.91E+08 6.29E+08
10/18/2011	1.22E+09 1.80E+07	7.71E+08 3.58E+08	1.40E+09 9.83E+08	1.28E+09 3.40E+09
11/8/2011	6.68E+09 1.31E+09	3.70E+09 5.46E+09	6.90E+09 3.11E+09	5.42E+09 4.27E+09

Note: bolded values indicate period without aeration

5.4.9. Effect of artificial aeration on Euglenophyceae, Synurophyceae and Chrysophyceae

In 2010, Euglenophyceae DWA occasionally grew when the lake was aerated, while a higher growth was observed during stratification in 2011 (Figure 65). The lack of the data in 2010 makes statistical analyses insufficient to compare both conditions. Among the sites in 2010, Euglenophyceae did not show consistent growth (Table 31). In 2011 Euglenophyceae were observed at all the sampling sites when the reservoir was not aerated (Table 32). Euglenophyceae growth rate has been found to be lower than that of diatoms, green algae, blue-green algae and Cryptophyceae (Safonova, 1987), which could explain their relatively slower growth in the HMD. They are more common for small eutrophic and rich in organic matter lakes and reservoirs (Bucka et al., 2000; Wołowski & Hindák, 2004). Due to the lack of consistent data, no further analyses were made.

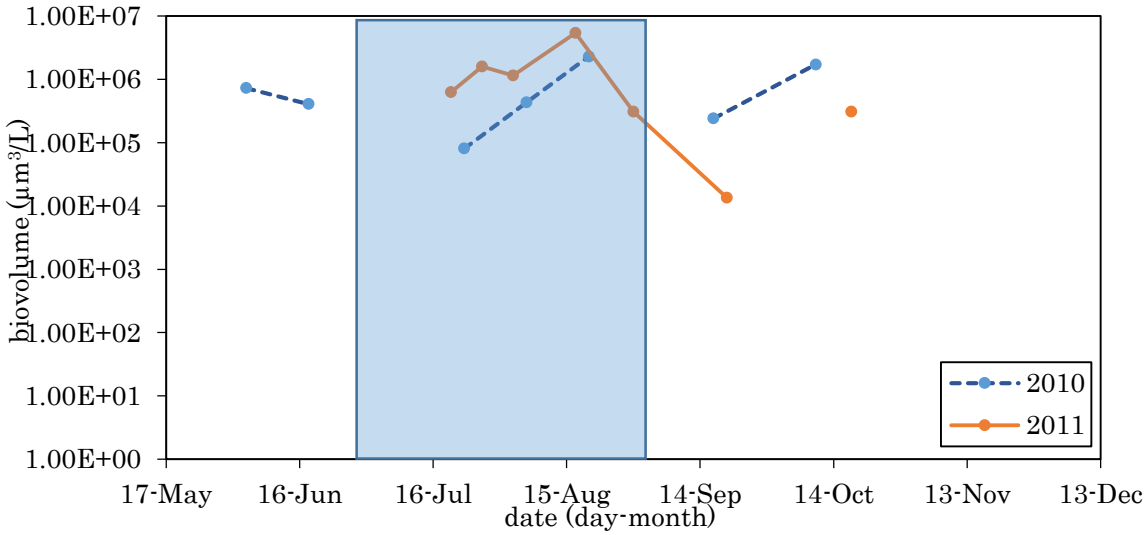

Figure 65. Depth-weighted average biovolume of Euglenophyceae Site A: 2010 with aeration in entire season and 2011 without aeration in shaded area.

Table 31. Euglenophyceae depth-weighted averaged biovolume and Standard deviation (STD), 2010

date (mo/day/yr)	Euglenophyceae biovolume (average ± STD), µm3/L			
	Site A	Site B	Site C	Site D
6/4/2010	7.26E+05 1.18E+06		4.22E+04 1.09E+05	
6/18/2010	4.06E+05 1.10E+06	3.18E+05 8.90E+05	2.59E+06 2.22E+06	
7/9/2010		7.84E+07 5.41E+08	1.05E+06 2.29E+06	
7/23/2010	8.07E+04 2.41E+05	4.34E+05 1.47E+06		4.81E+07 1.84E+08
8/6/2010	4.31E+05 5.37E+05	1.63E+06 3.22E+06	2.24E+06 1.69E+06	3.90E+05 8.61E+05
8/20/2010	2.29E+06 1.23E+06	3.59E+05 1.29E+06	2.04E+06 1.97E+06	2.06E+06 4.29E+06
9/3/2010			3.15E+06 5.02E+06	
9/17/2010	2.40E+05 5.19E+05	8.79E+05 1.39E+06	3.00E+05 5.84E+05	5.16E+05 1.50E+06
10/1/2010	1.71E+06 2.26E+06			
10/15/2010				

Table 32. Euglenophyceae depth-weighted averaged biovolume and Standard deviation (STD), 2011

date (mo/day/yr)	Euglenophyceae biovolume (average ± STD), µm3/L			
	Site A	Site B	Site C	Site D
6/30/2011				
7/13/2011				
7/20/2011	**6.29E+05 (1.46E+06)**		**2.08E+05 6.02E+05**	
7/27/2011	**1.60E+06 2.26E+06**		**6.54E+05 1.16E+06**	**1.91E+06 1.98E+06**
8/3/2011	**1.15E+06 2.94E+06**	**5.35E+06 8.23E+06**	**6.58E+06 1.73E+07**	**1.16E+07 2.03E+07**
8/17/2011	**5.41E+06 4.65E+06**	**5.38E+06 1.95E+07**	**5.25E+06 1.60E+07**	**2.93E+07 1.01E+08**
8/30/2011	**3.08E+05 4.72E+05**		**5.47E+05 1.65E+06**	**1.02E+05 2.73E+05**
9/20/2011	1.35E+04 3.40E+04	1.49E+06 3.15E+06	8.80E+04 2.09E+05	
10/4/2011				
10/18/2011	3.08E+05 2.67E+05			
11/8/2011				

Note: bolded values indicate period without aeration

Among Class Synurophyceae, *Mallomonas* sp. was the only genus found in the HMD and *Mallomonas* sp. are common for eutrophic lakes (Kristiancen, 1986; Silver, 1991, Wei & Yuan, 2000). *Mallomonas* sp. was frequently found in the HMD, when the reservoir was aerated and the nutrient availability was higher (Figure 66). *Mallomonas* sp. (Figure 67) was found to grow better at warmer temperatures (Kristiansen, 2005). However, many genera have been founded differently distributed along the different temperatures (Silver, 1995). Due to the lack of consistent data, no further analyses were made.

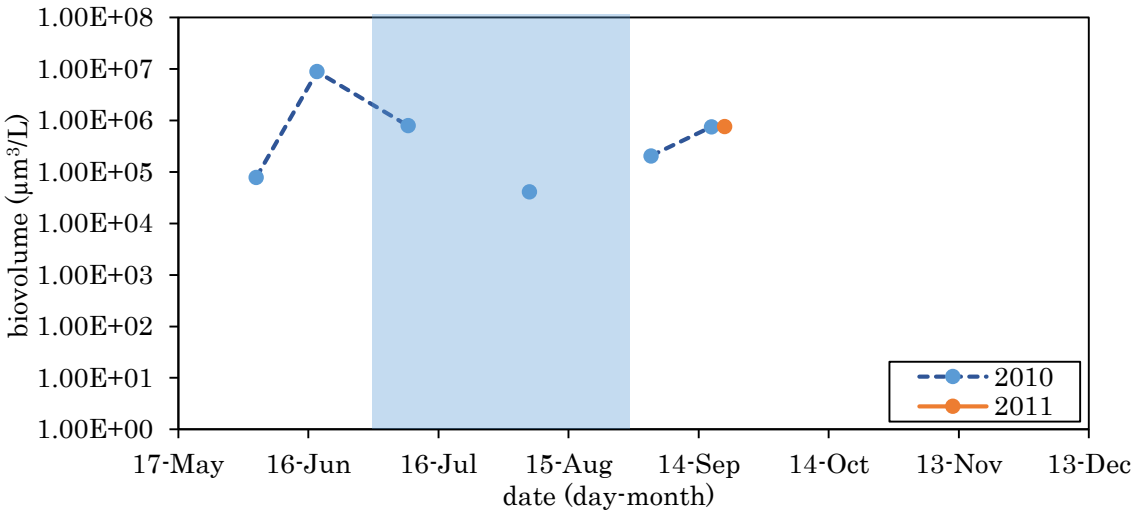

Figure 66. Depth-weighted average biovolume of Synurophyceae at Site A: 2010 with aeration during entire season and 2011 without aeration in shaded area.

Figure 67. *Mallomonas* sp.

Among Class Chrysophyceae, *Dinobryon* sp. was the only genus found in the HMD. In 2010 *Dinobryon sp.* was detected once at all the sampling sites. Although nutrient availability was highest when reservoir was aerated, *Dinobryon* sp. did not show a sustained growth (Figure 68). *Dinobryon* sp. (Figure 69) growth is typical in eutrophic lakes (Nixdorf et al., 2003). However, *Dinobryon* sp. was not found in lakes and reservoirs with high concentrations of P, which probably are inhibitory for that genus (Lehman, 1976). It's absence in the water column when the phosphorus concentrations were highest is an evidence that the higher P does not favor higher growth of *Dinobryon* sp. *Dinobryon* sp. has

a relatively slower growth rate than other classes, which probably makes this genus less efficient in taking up nutrients.

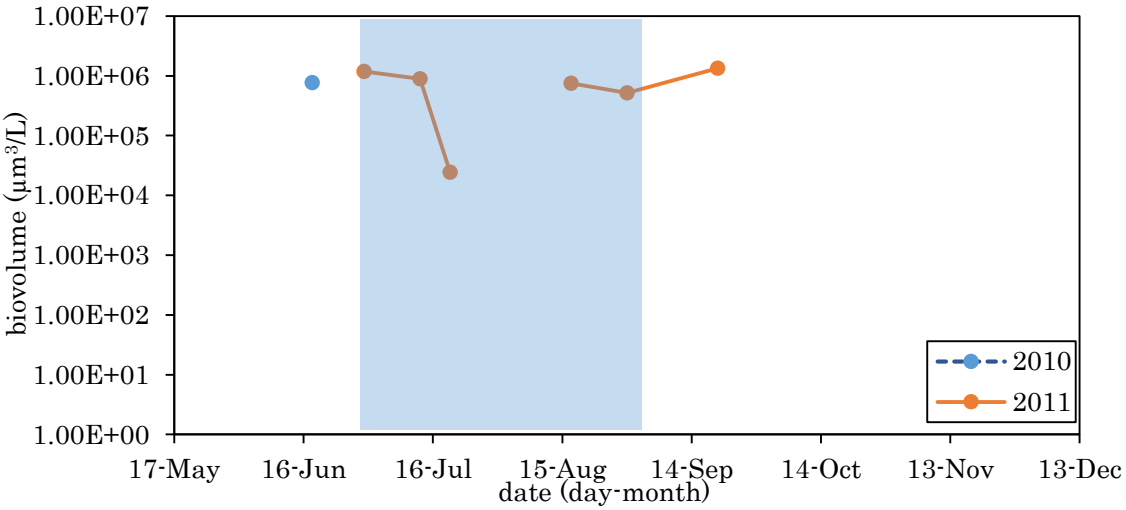

Figure 68. Depth-weighted average biovolume of Chrysophyceae at Site A: 2010, with aeration during entire season and 2011 without aeration in shaded area.

Figure 69. *Dinobryon* sp.

In 2011, *Dinobryon* sp. was more often present in the water column. In early July, when the reservoir was aerated, *Dinobryon* sp. was present at almost the same amount as in 2010 (Figure 70). However, when aeration was stopped its biovolume rapidly decreased. A week after the decrease *Dinobryon* sp. showed quite a constant growth until aeration was turned on again. In addition, to lower P requirements, *Dinobryon* sp. can utilize organically bound phosphate as glycerophospate (Lehman, 1976) and organic nitrogen forms as urea and glycerine (Lehman, 1976; Dagett et al., 2015). Thereby, its ability to utilize these

organic forms of both essential nutrients suggest that *Dinobryon* sp. is able to grow when decomposition of previous growing phytoplankton classes releases nutrient products in the water.

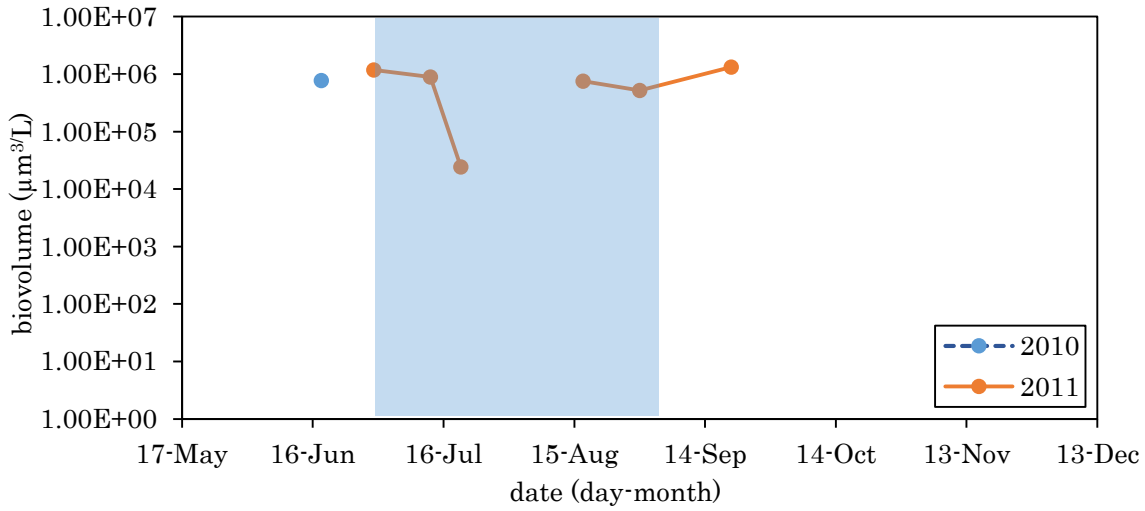

Figure 70. Depth-weighted average biovolume of Chrysophyceae at Site A: 2010 with aeration during entire season and 2011 without aeration in shaded area.

5.4.10. Effect of artificial aeration on total phytoplankton biovolumes

To summarize the effect of artificial aeration on the total phytoplankton growth, the DWA phytoplankton biovolumes of all classes were added together to calculate the total phytoplankton biovolume for each year. As can be seen from Figure 71, the total phytoplankton biovolume at Site A in 2010, when the reservoir was artificially aerated, was 3 times higher in comparison with the biovolume in the period without stratification in 2011. Results from WMW show a significant between both periods ($p<0.05$, Table E115), which confirms that a higher phytoplankton growth resulted due to aeration. No significant differences were found in phytoplankton biovolumes at Sites B ($p=0.18$), C ($p=0.71$), or D ($p=0.90$) (Tables E116, E117, and E118, respectively).

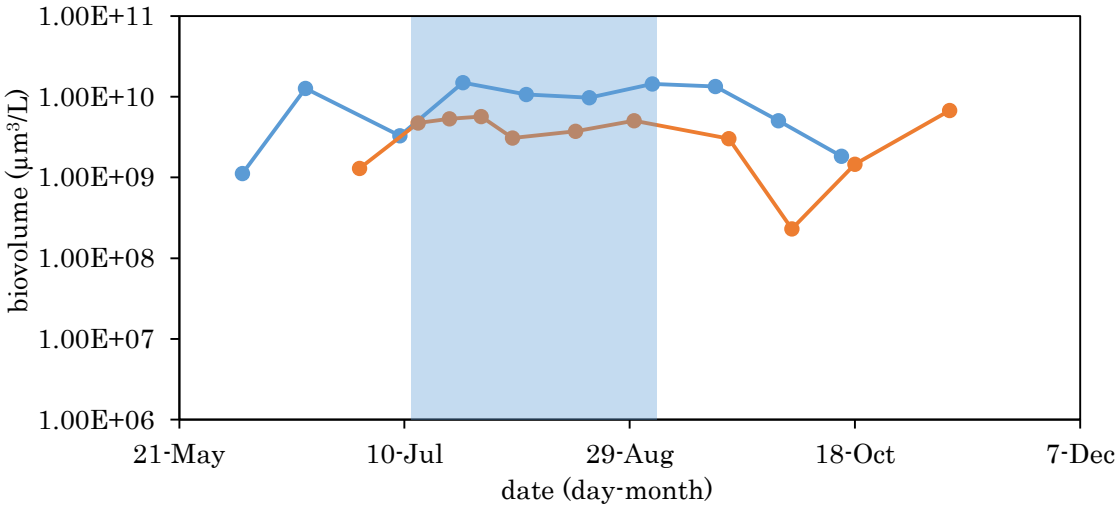

Figure 71. Depth-weighted average biovolume of total phytoplankton at Site A: 2010, with aeration during entire season and 2011, without artificial aeration in shaded area.

5.4.11. Effect of destratification on Diversity and Similarity

Diversity of the organisms (phytoplankton) is commonly measured as a species richness (number of species) and a species evenness (how relative abundance or biomass is distributed among genera) (Purvis & Hector 2000; Magurran, 2004). Understanding biodiversity and its distribution across space, time, and along environmental gradients is crucial in order to assess the ecological status of the ecosystem health.

In early summer, when reservoir was aerated, the diversity and similarity indices based on genera counts were initially low due to the peak of diatoms' genera *Fragilaria* sp. and *Stephanodiscus* sp.. After the diatoms declined, the diversity started to increase and showed maximum values in September (Table 34). The increase of diversity among the phytoplankton coincided with the observed increase of nutrient availability in the HMD. The diversity in the HMD was due to co-existence of several species of diatoms and Chlorophyceae, Cryptophyceae, and Cyanobacterial genera. The decrease in the diversity and the evenness reflected the change in phytoplankton population structure, which corresponded to the observed change in dominance passed from diatoms to dinoflagellates.

However, the values of the evenness remained low and barely exceeded values of 0.35, which is close to uneven distribution of individuals. This further indicates that two or more genera successfully dominated in the phytoplankton community.

Table 33. Total genera, total individuals, Pielou's Evenness Index and Shannon-Weaver Index for the phytoplankton structure at Site A (2010) with aeration during the entire sampling period

Sample	Total genera	Total individuals	Pielou's Evenness Index	Shannon-Weaver Index
6/4/2010	19	463035	0.2587	1.099
6/18/2010	26	6364025	0.2482	1.167
7/9/2010	26	565990	0.2824	1.327
7/23/2010	27	1313870	0.2799	1.331
8/6/2010	13	1167109	0.3125	1.156
8/20/2010	23	1338430	0.2982	1.349
9/3/2010	16	1257451	0.3917	1.567
9/17/2010	24	1510020	0.3312	1.519
10/1/2010	26	1639914	0.2086	0.9804
10/15/2010	20	663517	0.2502	1.081

However, when the aeration was stopped, reduced mixing and decreased nutrient availability causing a rapid decrease in diversity (Table 35). This decline of diversity was also accomplished by a decreasing in evenness, indicating uneven distribution among the phytoplankton community. The decrease of evenness also indicated increase of a dominance of Cyanobacteria in the reservoir after the one set of stratification. The decrease of diversity shows the competitive success of these genera. The increase of diversity after the collapse of Cyanobacterial genera is probably related to the episodic increase of the growth of some genera such as Chlorophyceae, Cyanobacteria, and mostly dinoflagellate increase at that time. However, over the next week diversity index again decreased to the levels similar to the 2010, when reservoir was aerated. These results indicate that the condition in the reservoir remained limited for the growth of the phytoplankton. The next increase of diversity was marked by increase of dinoflagellates.

Table 34. Total genera, total individuals, Pielou's Evenness Index and Shannon-Weaver Index for the phytoplankton structure at Site A (2011) with no aeration marked with bolded values

Sample	Total genera	Total individuals	Pielou's Evenness Index	Shannon Index
6/30/2011	19	463035	0.2872	1.174
7/13/2011	26	6364025	0.2309	1.072
7/20/2011	**26**	**565990**	**0.149**	**0.7087**
7/27/2011	**27**	**1313870**	**0.067**	**0.3107**
8/3/2011	**13**	**1167109**	**0.394**	**1.757**
8/17/2011	**23**	**1338430**	**0.2698**	**1.297**
8/30/2011	**16**	**1257451**	**0.3221**	**1.581**
9/20/2011	24	1510020	0.3357	1.475
10/4/2011	26	1639914	0.2846	1.138
10/18/2011	20	663517	0.1523	0.6982

5.5. Discussion

The aim of CHAPTER 5 was to investigate the effect of artificial aeration on phytoplankton growth. During spring and early summer, like in most temperate lakes, increase of water temperature, light intensity, and daylength combined with increase in nutrient availability triggered a gradual increase of phytoplankton growth in the HMD. Total phytoplankton population in the HMD had two clearly distinguished maximums. After the initial spring maximum of phytoplankton population growth, a sharp decrease in growth followed, before it increased again in summer, reaching the summer maximum. These observations were in general accordance with the statement in the PEG model. Whether the phytoplankton biomass variations are controlled by temperature, stratification, or light regime is difficult to establish since these factors are interrelated (Levasseur et al 1984; Sommer et al., 1986).

The classic assumption that temperature tolerance of phytoplankton may trigger seasonal succession has declined in importance (Sommer, 1987; Reynolds, 2006). Winter and spring phytoplankton species or so called "cold-water species" should be expected to have short growth periods. For example, cool temperatures and lack of stratification are

implicated as primary factors determining diatom success (Köster & Pienitz, 2006; Ferris & Lehman, 2007). However, in eutrophic lakes those "cold-water species" were found growing in summers, when nutrients were higher. *Asterionella formosa, Fragilaria crotonensis,* and *Dinobryon* were observed also in Lake Constance in the summer (Bürgi & Lehn, 1979; Salmazo, 2002). Laboratory experiments showed that the dominant phytoplankton taxa remained consistent at all water temperatures in treatments with no nutrient enrichment, but shifted to diatoms in treatments with nutrient additions (Deng et al., 2014). Other studies have showed that rising temperatures enhance Cyanobacterial biomass and dominance along a range of latitudes (Peperzak, 2003; Paerl & Huisman, 2008; O'Neil, 2012). However, Reynolds (1997) showed that increase of temperature increased twice a maximum growth rate of *Microcystis* as well as of *Scenedesmus* and *Asterionella*. Similar trends in temperature growth rates between three Cyanobacteria (*Microcystis, Merismopedia and Oscillatoria*) and diatom (*Aulacoseira*) were observed by Coles and Jones (2000). In addition, culture experiments show that *Aphanizomenon flos-aquae* could grew at above 8°C with an optimum temperature ranging from 23 to 29°C and survived at 5°C for at least 25 days (Tsujimura et al., 2001). In contrast, Moss et al. (2003) did not observe change in Cyanobacterial abundance with temperature.

In the HMD variations of water temperature over time during 2010 and 2011 showed similar patterns typical for temperate lakes; however, both years' variations in DWA biovolumes of phytoplankton classes over time showed different successional patterns. Therefore, the effect of temperature is not excluded but is assumed less important to explain seasonality of phytoplankton in the HMD. Still, rising of temperature certainly will effect phytoplankton community in indirect way. For instance, reduced mixing and stratification have been found to effect on phytoplankton growth and shift species

composition in phytoplankton community (Sommer, 1987; Huisman et al., 2004; Lampert, 2007). The ability of artificial aeration to eliminate thermal-stratification and create a mixing condition for phytoplankton to grow is often reported (Visser et al., 1996; Heo &Kim, 2004). Increased vertical mixing of water column has been reported to decrease the light intensity, increase nutrient availability, and reduces sedimentary losses by resuspension of cells (Sommer, 1987). Eliminating of summer thermo-stratification in the HMD, due to artificial aeration, changed overall phytoplankton composition in the HMD. In comparison with phytoplankton succession described in studies that showed phytoplankton growth decreased after summer stratification due to depletion of nutrients (Sommer et al., 1986; Haszar et all., 2003; Arhondisis et al, 2004), Chl-*a* and biovolume data from the HMD confirmed a higher, prolonged and sustained phytoplankton growth in summer. This is because continuous mixing and continuous addition of nutrients to the water column, due to aeration, undoubtedly favored phytoplankton growth in the HMD. Higher phytoplankton density in the reservoir was visible by the unaided eye (Figure 72).

Figure 72. Phytoplankton growth during aeration in the HMD (2010).

In 2010, when lake was aerated, phytoplankton biomass exhibited a spring maxima of diatoms' bloom, followed by increased biovolume of dinoflagellates. The described seasonal sequence in the HMD, passing from diatoms to dinoflagellates observed in the first year of aeration, was interrupted in the second year of aeration by Cyanobacteria dominance. Diatoms and dinoflagellates, which were the dominant classes both years, expressed the most prominent effect of aeration in the HMD. Results from analyses of biovolume variations over time showed that diatoms were the dominant phytoplankton classes in spring both years (2010 and 2011), suggesting that the artificial aeration did not change their typical spring and early summer maximum growth but enhanced their growth during summer in the HMD.

Instead of decreasing and reaching a minimum abundance in summer months as described in the PEG model due to Si-depletion and reduced mixing, the diatoms biovolume were still present in the water column in a higher densities than non-aerated period. In comparison with non-aerated condition in the HMD, diatoms remained significantly higher in summer months when the reservoir was aerated. The benefit of mixing to diatoms has been demonstrated in other studies (Visser, 1996; Heo & Kim, 2004), in which diatoms increase was explained with the fact that mixing from aeration kept diatoms suspended in the water column (Reynolds, 2006). Heo and Kim (2004) also discussed that artificial mixing in Lake Dalbang, the period of spring mixing was essentially carried into the summer months allowing diatoms to continue growing. In addition to the benefits of mixing, the diatoms' higher growth in the HMD coincided with the increased nutrient availability due to aeration. This results are in consistency with the studies showed that higher P inputs (Lotter, 1998) and increase of organic matter in sediments (Wolfe et al., 2001, 2002) favored higher diatoms' growth. The current study reveals that sediments are a

major source of nutrients and rich in organic matter. Decomposition of organic matter that results in release of nutrients is faster under aerobic condition (Kristensen et al., 1995; Geurts et al. 2010). Hawkins and Griffiths (1993) reported that diatoms dominated during artificial aeration as long as enough Si was available. Thereafter, higher nutrient availability, due to their release from sediments coupled with the mixing, due to artificial aeration, prolonged diatoms' growth in summer months.

Similar higher nutrient availability due to artificial aeration resulted in a significantly higher dinoflagellate growth. Dinoflagellates dominated both years in the HMD. Dinoflagellates have a relatively slow growth in comparison to diatoms and usually dominate in the late summer (Margalef, 1978; Summer, 1985; Reynolds, 2006). However, dinoflagellate biovolume data from the HMD show that dinoflagellate growth shifted earlier in time when nutrients availability was highest due to aeration. These findings are in agreement with a study conducted by Fisher et al. (2013), who found that dinoflagellates dominate when the bioavailable nutrients are highest. These results suggest that increased continuous addition of nutrients, due to mixing were able to maintain the higher growth of dinoflagellates population.

Although the mixing and higher nutrient availability were able to supported higher growth of both diatoms and dinoflagellates, the shift from one group to another persisted. The most viable factor causing the replacement of diatoms by dinoflagellates is differences in their nutrient uptake strategies (Litchman 2007; Litchman & Klausmeier 2007; Litchman & Pinto 2010). According to the results of the phytoplankton kinetics studies summarized in Table 1 (CHAPTER 3), diatoms grow fast but also have relatively lower-saturation constant for nitrogen than dinoflagellates (Helterman & Toetz, 1984; Hu, 1993). Lower-half saturation constant makes diatoms more competitive in N-limited condition.

Dinoflagellates, on the other hand, have a slower growth rate and higher half-saturation constant, which makes them poor competitors for nutrients when compared to diatoms (Pollingher 1988; Thang, 1996) and other eukaryotic phytoplankton (Litchman, 2007; Litchman & Klausmeier, 2007). Analyses of TDIN concentrations in the HMD show that TDIN hardly exceeded 0.20 mg/L, indicating that N is a strong limiting factor for the growth of both diatoms and dinoflagellates. However, dinoflagellates' was found to dominate at low N:P ratios (Lieberman et al., 1994; Lavinie & Schindler, 1999). It is well documented that some dinoflagellates can supplement their nutrient requirements through phagocytosis (Sanders., 1991; Hancen & Calado, 1999; Levine & Schindler, 1999, 1973; Stoecker, 1999; Li et al., 2000, Clegg et al., 2004; Pérez-Martínez & Sánchez-Castillo, 2002). Nutrient-limited conditions have been also known to trigger a phagocytosis response in dinoflagellate species, with N and P subsequently sourced from ingested bacteria and other particulate organic forms (Nygaard & Tobiesen, 1993; Caron et al., 1990; Li et al., 2000). We do not have evidence for phagocytosis, but their higher and consistent growth under strong N-limitation in the HMD suggests that dinoflagellates adopted phagocytosis as an alternative mode of nutrition.

It is also well known that the low N:P ratio is an important predictor related to the Cyanobacteria growth in the lakes and reservoirs (Smith, 1983; Schindler et al., 2008). Although the N:P ratio in the HMD was consistently below 2 during both years, Cyanobacteria did not dominate in 2010, when the lake was aerated, but showed a gradual increase in the mid-summer. This is an indication that aeration more likely will promote Cyanobacteria growth.

As demonstrated in PEG model (Sommer et al., 1986), as well as in other studies (Fisher et al., 2013) and results from kinetic studies, Cyanobacteria similar to

dinoflagellates (Table 1. CHAPTER 2) are among the main competitors during the late part of the warm summer when lake is stratified and surface layers are usually nutrient depleted. However, the analyses of phytoplankton class distributions over time in HMD indicate that both started to grow earlier in time when reservoir was aerated and nutrients were continually added to the water column. Although N_2-fixing species, which dominated among Cyanobacteria in the HMD, may survive in N-limited condition through N_2-fixation some studies showed N-limitation does not necessary mean that fixation was taking place (Ferber et al., 2004; Wood et al., 2010). Instead ammonia-nitrogen is an energetically efficient inorganic nitrogen source that has been found to be a favorable nitrogen form for Cyanobacteria (Oliver & Ganf, 2000; Flores & Herrero, 2005). Those are evidance that Cyanobacteria may not gain their competitive dominance in N-limited lakes through N-fixation alone, but through their highly competitive ability to sequester ammonium.

However, it was revealed in this study that nitrification process was greatly enhanced by the artificial mixing in the HMD through which ammonia is converted into nitrate. Change in the inorganic nitrogen source in the reservoir probably is another factor influencing phytoplankton community and competition between species, because phytoplankton had to rely mostly on nitrite as nitrogen source. A studies show that Cyanobacteria are less efficient to utilize nitrate (Blomqvist et al, 1994), while other studies showed that dinoflagellates prefered nitrate as a nitrogen source (Lingström, 1991; Dominges et al., 2011). The preference to nitrate utilization an exception of the general rule that ammonium is a prefered nitrogen source by phytoplankton because it is energeticaly cheaper. Competition fo nitrate probably resulted in dinoflagellates dominance over Cyanobacteria when lake was aerated. Therefer this is another evidence of how aeration

may change nutrient condition for some phytoplankton genera makes them less or more competative for limited resources.

However, if Cyanobacteria extend their growth before dinoflagellates, as was observed in during 2011 when reservoir was aerated, Cyanobacteria are more likely to dominate in the reservoir. This finding became more evident in 2011 when in the beginning of June, when reservoir was aerated; N_2-fixing Cyanobacteria formed a bloom in the HMD (Figure 73). Cyanobacteria dominated over the other phytoplankton classes in the HMD in the second year of aeration, because of their ability to fix N_2-fixing (Smith, 1983; Schindler et al., 2008) and lower half-saturation constant for N uptake (Halterman & Toetz, 1984), in addition to increased P availability caused by aeration. Thereby, our results suggest that the artificial aeration would likely favor Cyanobacteria growth. Nevertheless, aeration did not successfully solve the problem with Cyanobacteria growth in the HMD (more about Cyanobacteria growth will be discussed in the next CHAPTER 6).

Figure 73. Cyanobacterial bloom during aeration in 2011

For the rest of the phytoplankton classes, the observed seasonal succession in the HMD did not follow the PEG succession. For example, the green algae, which was described

as a major class in the PEG model in the early phases of stratification (Sommer, 1986), in the HMD did not exceeded more than 10% of the total DWA biovolume under both aerated and non-aerated conditions. Most of the colonial green algae, similar to diatoms, require mixing to remain suspended in the water column (Reynolds, 2006). The increase of green algae growth has been observed in other artificially mixed lakes (Steinberg, 1983; Visser et al. 1996; Jungo et al., 2001). If the mixing of aeration is expected more likely to decreased sedimentation losses, decreased growth of green algae during summer months in the HMD, indicates that green algae growth is limited due to other factors such as nutrient limitation. As previously indicated, the HMD experienced a strong N-limitation both years. Values of TDIN concentrations for the HMD of 0.2 mg/L also were lower compared with 2.6 mg/L reported by Visser et al (1996) in which green algae were reported to increase with aeration. A few studies also indicate that green algae are characterized by a higher growth rates and have a higher nutrients demand (Reynolds 1988; Sgndergaard et al. 1990; Jensen & Andersen 1992). Although increased mixing and P-availability was higher during aeration, the strong N-limitation in the HMD appear to be a factor causing green algae to decrease.

The finding about unbalanced N and P supply in the HMD is important because although nutrient availability was higher, due to aeration resulting in a higher phytoplankton growth, N-limitation in the reservoir trigged lower growth in some of the genera. The arrangement of genera and their requirements to the nutrients investigated in this study, suggest that higher nutrient availability in addition to N-limitation in the HMD are the important factors in determine change in abundance of major genera. The lower growth rates and uptake kinetics of some genera due to N-limitation, indeed affects the replacement and progression of species. In addition to the enhanced phytoplankton growth

due to higher nutrient availability, the mixing generated from aeration affected vertical distribution of phytoplankton. The concentration profiles based on Chl-*a* and phytoplankton biovolumes of all classes show that the phytoplankton was dispersed deep in the water column. Therefore, mixing was able to reduce surface blooms of phytoplankton. However, observed equal distribution of nutrients was over the water column implement that were available for the phytoplankton at any time and any depth. On the other hand, the lack of horizontal differences in phytoplankton biovolume between the sampling sites that is revealed under both condition could be explained by the relatively small size of the reservoir investigated.

5.6. Conclusions

- Chl-*a* and biovolume data show a higher phytoplankton growth during aeration because of the increased nutrient availability due to mixing caused by aeration. Artificial aeration did not reduced phytoplankton growth.
- Chl-*a* and biovolume data show that the mixing and higher nutrient availability, due to aeration, not only increased but in addition prolonged higher growth in summer months when compared to other natural lakes
- Phytoplankton classes (diatoms, dinoflagellates, and Cyanobacteria) growth was shifted earlier due to continuous addition of nutrients in the water column.
- Although P was added continuously to the water column and was able to supports higher growth of the phytoplankton genera, the strong N-limitation in the reservoir is a growth limited factor controlling the growth and shift of genera in their seasonal succession. For example, green algae did not dominated in the HMD has been observed in other artificially mixed lakes.

- Phytoplankton analyses also demonstrate that the effects on aeration on reducing Cyanobacterial growth are less encouraging. Our results suggest that the aeration creates conditions that more likely will favor Cyanobacterial growth. Detailed discussion of effects of aeration on Cyanobacterial growth will be presented in the next CHAPTER 6.

CHAPTER 6. IMPACT OF ARTIFICIAL AERATION ON CYANOBACTERIA GROWTH

6.1. Abstract

Increase of Cyanobacterial growth and frequent blooms due to eutrophication has received a special concern. The release of offensive odor and taste compounds and ability of some Cyanobacteria to produce potent toxins associated with human and animal health problems is a threat for water quality. Artificial aeration, which was employed with the main purpose to increase dissolved oxygen concentrations in a small reservoir in North Dakota and to reduce nutrient release from sediments, was also used to control Cyanobacterial blooms. However, research studies have shown the aeration is not always an effective method to reduce Cyanobacterial growth. This study was undertaken to investigate effects of aeration on the Cyanobacterial growth. Samples for nutrients and phytoplankton analyses were taken under aerated and non-aerated conditions from a small artificially aerated reservoir in North Dakota. Artificial aeration destratified the water column, eliminated nutrient concentrations gradients, and dispersed phytoplankton deeper in the reservoir. The results also show that nitrogen-fixing Cyanobacteria dominated and formed a bloom when reservoir was aerated, but the bloom collapsed under non-aerated condition. Cyanobacteria dominated because of its relatively fast growth rate at low inorganic nitrogen concentrations and because of continuous addition of phosphorus, which release from sediments was enhanced by aeration.

6.2. Introduction

Eutrophication caused by excessive input of nitrogen and phosphorus (N and P) is a natural process that typically occurs as lakes age. However, human activities cause acceleration of eutrophication (called "cultural eutrophication"). Common symptoms related to eutrophication include excessive algal blooms, especially those of Cyanobacteria.

Cyanobacterial excessive growth and blooms are now recognized the most visible symptoms of accelearted eutrophycation of freshwater ecosysytems (Moss et al., 1996, Schindler et al., 2008). Major problems and concerns associated with Cyanobacterial blooms include reduced water clarity, offensive odor and taste from live and dead Cyanobacterial biomass, and low and even complete consumption of DO near the bottom of the water bodies, which subsequently may result in fish kills (Smith et al., 1999; Schindler, 2012). In addition, toxins released by some Cyanobacteria species are harmfull for human and aquatic biota (Chorus, 2001; Downing et al., 2001; Scheffer, 2004; Codd et al., 2005). Threafor, frequent and prolonged cyanobacterial occurances have become a threat to water quality leading to reduction of designated uses of lakes and reservoirs such as drinking water supply, recreation, irrigation, fishing and swimming.

Because of the water quality problems Cyanobacteria pose, a comprehensive approach to research and management of excessive cyanobacteria growth has received extensive attention. Controlling external imput of nutrients (external loading) is assumed as a strategy to reduce phytoplankton blooms. However, the reduction of the external loading) did not result in immediate success in reducing Cyanobacterial growth (Schindler, 2012). Nutrients previously accumulated in the water bodies are recycled back to the overlying water (internal loaading) and are able to support phytoplankton growth. Therefore, internal loading is an important factor that could accelerate process of eutrophication (Carpenter et al., 1998). Reducing nutrient internal loading has become a focus in management practices to control nutrient release from sediments and restore water quality in lake ecosystems.

Considering the chemical and biological mechanisms of N and P release from sediments, it is important to realize that although the microbial denitrification could

remove N from the lake and derive N-limitation (McCarthy et al., 2007), there are no significantly effective or proven processes for P removal. Subsequently, P accumulates in the lake, which in turn cause unbalance and decrease of N:P ratio a lake. The lakes and reservoirs with lower N:P ratios are frequently dominated by Cyanobacteria because some are able to fix atmospheric nitrogen (Smith, 1983; Smith et al., 1995; Downing et al., 2001; Havens et al., 2003).

Artificial aeration has been commonly employed as a management technique with the purpose to eliminate thermal stratification, increase dissolved oxygen on the bottom of the lakes, and to reduce nutrient release. Results from studies investigating effectiveness of aeration to control Cyanobacteria growth showing different results. Artificial aeration was found successful to prevent Cyanobacterial surface blooms of *Microcystis* sp. (Visser., 1996; Jungo et al, 2001). Visser et al (1996) demonstrated that mixing due to artificial disturb *Microcystis'* buoyancy regulation, thereby limiting formation of the surface blooms. However, the total phytoplankton growth increased and population shifted to flagellates, green algae, diatoms, and N_2-fixing Cyanobacteria (Visser et al, 1996). Similar results was reported in study conducted by Heo & Kim (2004), in which diatoms replaced Cyanobacteria. Diatoms over competing and replacing Cyanobacteria was related to mixing, which creates condition that reduces sediment losses of diatoms and competition for the light between phytoplankton species (Heo & Kim, 2004). The authors in both studies reported no change in TP concentration; however, the increased phytoplankton biomass and shift in phytoplankton community suggest that mixing also changed in nutrient condition for phytoplankton growth.

Artificial aeration was proven less successful in reducing Cyanobacteria in other studies. Instead of decreasing, aeration resulted in increase of N_2-fixing Cyanobacteria

abundance and dominance (Antenucci et al., 2005; Burford & O'Donohue, 2006). Dominance was attributed to the ability of Cyanobacteria to compete for light (Antenucci et al., 2005; Burford & O'Donohue, 2006). While comparing aerated North Pine Reservoir with two adjacent naturally mixed lakes, Burford and O'Donohue (2006) found that the blooms appeared earlier in spring and were more severe and prolonged. Provided nutrient data indicate that in comparison with naturally mixed reservoirs, aeration decreased vertical and seasonal differences in nutrient concentrations; however, these seasonal changes in nutrient concentrations have not been considered.

The mixed results of these studies come from the diverse factors authors attribute Cyanobacterial dominance include elevated water temperature, low light, ratio of low total nitrogen:total phosphorus (TN:TP), high pH, ability to regulate buoyancy, storage strategy of P, low inorganic N, and trace elements (Hyenstrand & Blomqvist, 1998; Dokulil & Teubner, 2000). However, the most discussed advantage of Cyanobacteria commonly discussed over the other phytoplankton species is capability of some species to fix atmospheric nitrogen N_2, which allows them the opportunity to dominate at low TP:TN ratio (Smith 1983; Smith et al., 1995; Downing et al. 2001, Havens et al. 2003).

However, the critical ratio in which Cyanobacteria tend to dominate in lakes are found in range from 7 (Schindler, 1977), 29 (Smith, 1983), and 22 (Smith et al., 1995). In contrast Downing et al. (2001) proposed variations in TP concentration are a closely linked to Cyanobacteria blooms than the TN:TP ratio. Havens et al. (2003) suggested that a TDIN:SRP ratio less than 10:1 is a better predictor for N_2-fixing Cyanobacteria, rather than the TN:TP ratio. The lack of a clear relation between Cyanobacteria and N:P ratio suggest that use ratio only might not be enough to explain the variations in concentrations of N and P. The individual concentrations of nutrients are important because individual

concentrations of N and P are those that limit the primary production in freshwater ecosystems. Different phytoplankton species differ in their kinetics of nutrient uptake, assimilation, and storage capacities and therefore may have different nutrient requirements. To better understand how would nutrient availabilities and effect of artificial aeration will affect Cyanobacteria growth the current research was conducted in a small artificially eutrophic aerated lake in North Dakota.

6.3. Materials and Methods

6.3.1. Study site

The reservoir Heinrich-Martin Dam (HMD) is located in LaMoure County, ND and has a surface area of 0.08 km^2 with a maximum depth greater than 10 m (mean depth 4.30 m). North Dakota Game and Fish Department (NDGF) installed artificial aeration to improve low DO concentrations in the bottom of the impoundment. Results from research conducted in 2008, which determined effectiveness of artificial aeration on DO and water quality, showed that artificial aeration increased and maintained DO concentrations above 4.00 mg/L and prevented anoxic conditions near the bottom of the lake (Overmoe, 2008). However, qualitative observations showed that high phytoplankton growth persisted. Samples for phytoplankton biomass and speciation analyses were not taken.

Analyses of nutrients in CHAPTER 4 showed that although artificial aeration resulted in TP reduction by nearly 50%, significant P was still released in the water column. In addition, the mixing generated from artificial aeration resulted in nearly equal distribution of nutrients TDIN and SRP over the depths, making them more available for the phytoplankton growth. Analyses of nutrient concentrations show that the ratio N:P in the HMD was below 2, which is much lower than the ratio 7.2:1 accepted as an optimum for the phytoplankton growth (Redfield, 1934) indicating a strong N-limitation. These findings

are important because the low N:P ratios in lakes and reservoirs have been closely linked to the increased and frequent blooms and dominance of Cyanobacteria. The dominance of N_2–fixing Cyanobacterial species at the low N:P ratio was related to of their ability to fix atmospheric nitrogen (Smith, 1983; Smith et al, 1995; Schindler et al., 2008).

6.3.2. Sampling period, sampling sites and sampling frequency

To evaluate the impact of artificial aeration on Cyanobacterial growth in the impoundment, water samples were taken from four sample locations during growing season 2011 (Figure 6. CHAPTER 3). The sample locations, as shown in the HDM map, are spread out in the reservoir and were selected with considerations of water depth, flow pattern in the reservoir, and distances from air diffusors. Throughout the sampling period, the aeration was turned off for an extended period in the mid-summer. The samples were taken from multiple depths, biweekly during aerated, and weekly during non-aerated period (Detailed sampling schedule and depths available in Section 3.4. in CHAPTER 3)

6.3.3. Phytoplankton speciation, enumeration and biovolume determination

The 500 ml water samples for phytoplankton identification, enumeration, and biovolume analysis were preserved with Lugol's acid solutions in the field. Phytoplankton were counted and identified to the genera level under Inverted Microscopes (*Leica and Zeiss)*. For biovolume determination *ImageProPlus* 5.0 image analysis software was used following methodology developed for this study for phytoplankton biovolume estimation.(Detailed methodology for phytoplankton counting and specieation is available in APPENDIX C). The biovolume of each phytoplankton unit (cell, colony or filament) was determined applying one of the three developed methods depend on the phytoplankton unit: 1) area and depth method, 2) cross section area and length method, and 3) biovolume based on commonly accepted geometry. Next the unit volume was calculated by multiplying, the

unit volume by the abundance of these unit in the sample. (Detailed procedure for phytoplankton biovolume determination is available in APPENDIX D).

6.4. Results

In 2011 when the reservoir was aerated, Cyanobacteria depth-weighted averaged biovolume increased from 3.63E+06 µm³/L to 4.07E+09 µm³/L (Figure 74, a), indicating that population grew rapidly. At the beginning of July Cyanobacteria comprised 70% of the total phytoplankton abundance (Figure 74, b).

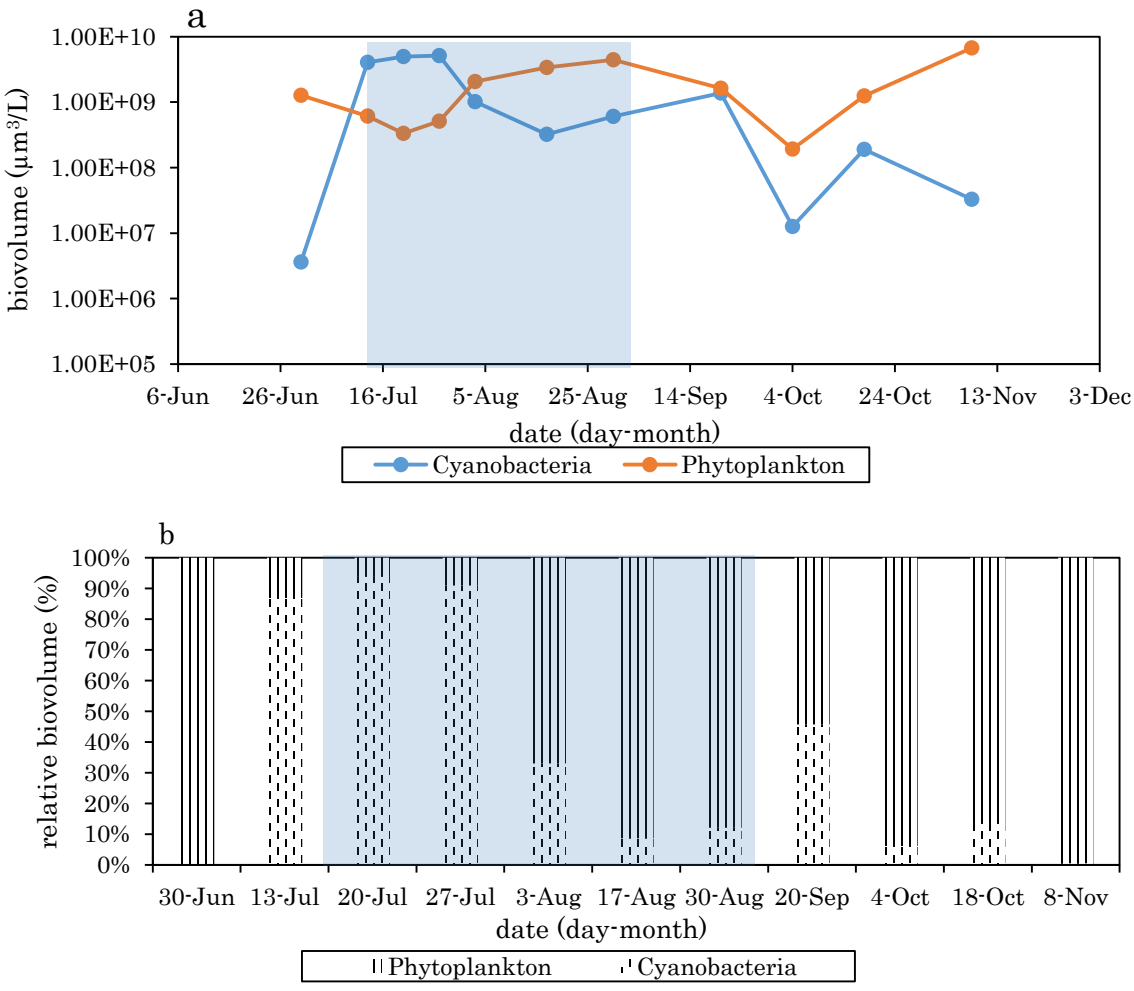

Figure 74. Cyanobacteria genera and phytoplankton at Site A (2011) with no artificial aeration in shaded area: (a) DWA biovolume and (b) relative biovolume.

The phytoplankton analysis (enumeration and biovolume determination) show that *Aphanizomenon* sp. and *Anabaena* sp. increased rapidly (Figure 75, a) and were identified as a major genera in the HMD. Together *Aphanizomenon* sp. and *Anabaena* sp. accounted for more than 80% of the total Cyanobacterial population in the reservoir (Figure 75, b). *Anabaena* sp. was a major genus at the end of June but soon at the beginning of July, it was replaced by *Aphanizomenon* sp.

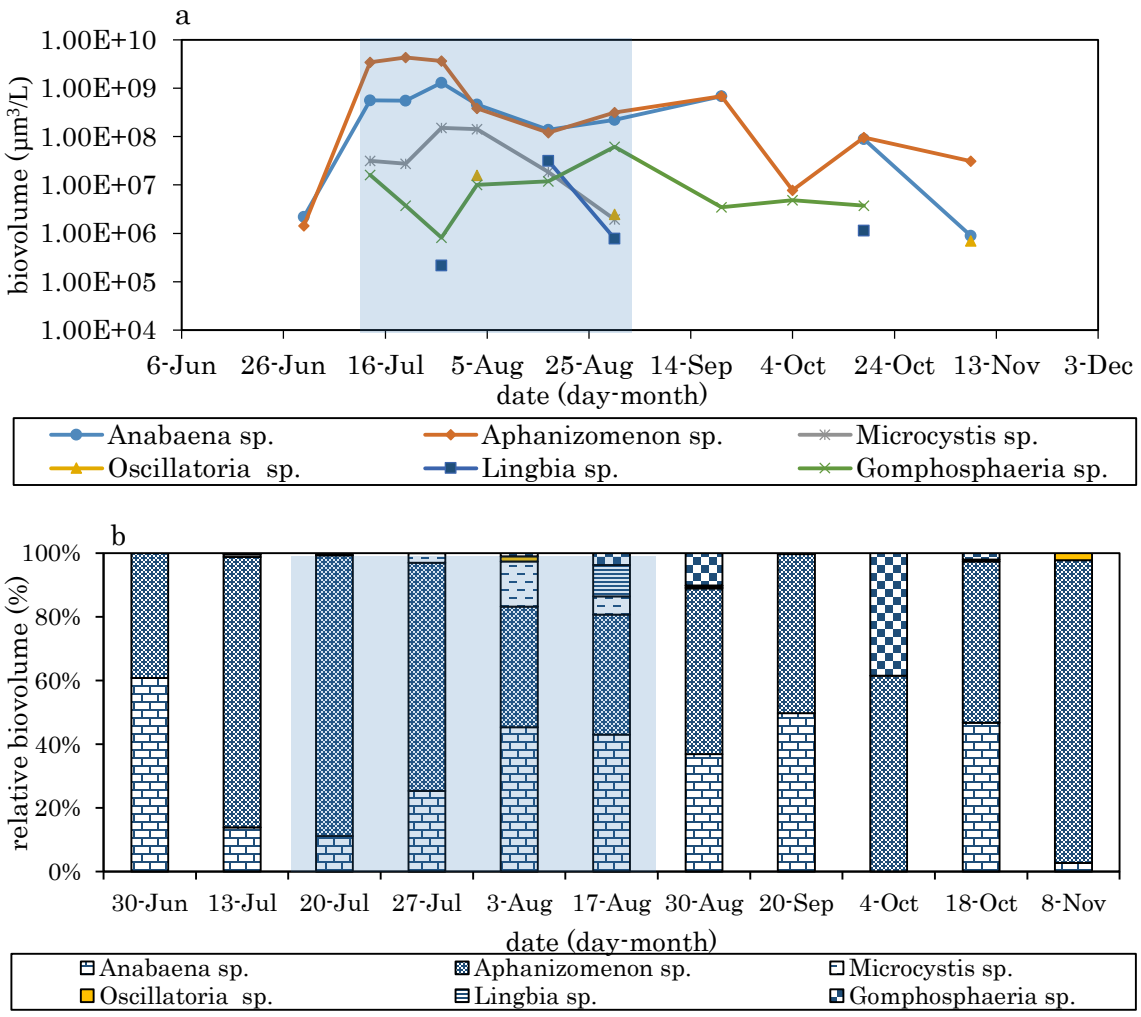

Figure 75. Cyanobacterial genera at Site A (2011) with no artificial aeration in shaded area: (a) DWA biovolume and (b) relative biovolume.

Discoloration of water and higher densities of Cyanobacteria genus suggested that bloom was developed (Figure 76). Both genera formed aggregates, which were easily

recognized with the unaided eye. *Aphanizomenon* sp. (Figure 77, a) formed flattened aggregates (Figure 77, b), each consisting of tens to hundreds of filaments, while *Anabaena* sp. (Figure 78, a) formed green cylindrical and ball like aggregates (Figure 78, b).

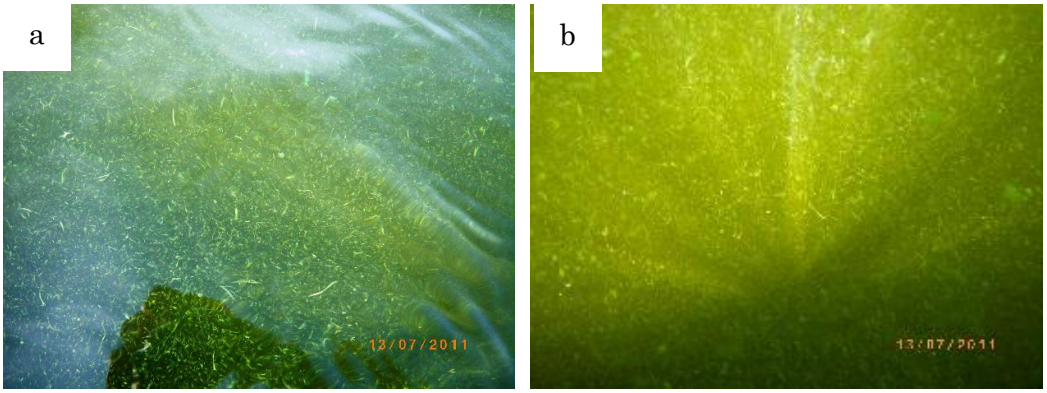

Figure 76. Cyanobacterial bloom observed in the HMD on July 13th, 2011

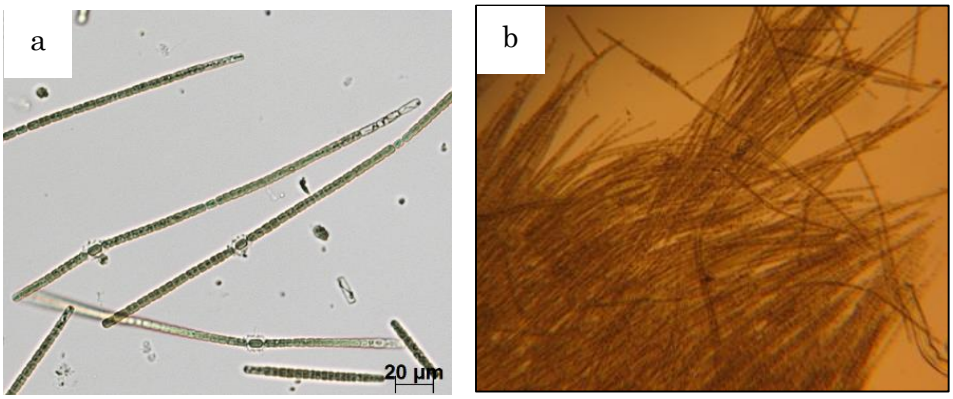

Figure 77. *Aphanizomenon* sp. (a) filament and (b) *Aphanizomenon* sp. aggregate

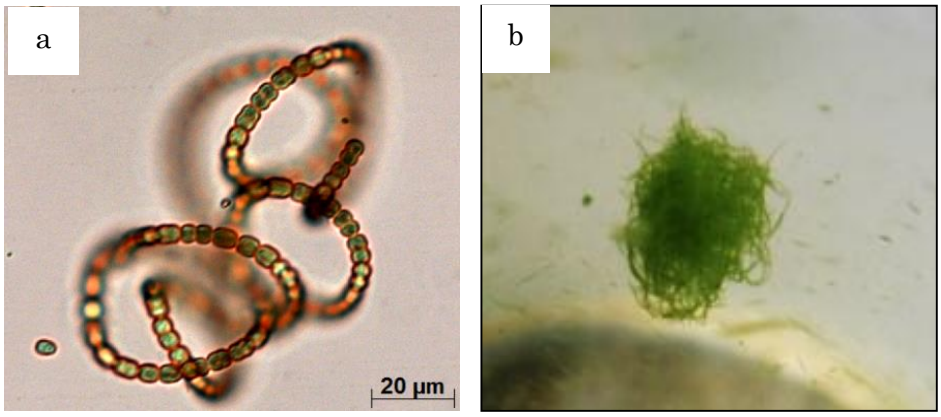

Figure 78. *Anabaena* sp. (a) filament and (b) *Anabaena* sp. aggregates

Aphanizomenon sp. and *Anabaena* sp. are among Cyanobacterial genera that are able to fix N_2 from the atmosphere. Indeed, this ability is considered an important physiological feature and is closely linked to their dominance at low N:P ratios (Smith 1983). The presence of heterocysts cells within *Aphanizomenon* sp. and *Anabaena* sp. (Figure 79, a and b) filaments most likely suggest N_2-fixation process (Kumar, 2010). Therefore the dominance of N_2-fixing Cyanobacteria is not surprising since the N:P ratio 2 in the HMD indicates a strong nitrogen limitation, which was not effected by operation of aeration.

Figure 79. Heterocysts (a) *Aphanizomenon* sp. and (b) *Anabaena* sp. Heteocycsts are indicated with red arrows

On July 13th, 2011 managers of the reservoir decided to turn off the aeration. The decreased mixing of the water column after stopping aeration resulted in of weak thermocline (Figure 9. CHAPTER 4). Over the next two weeks, the increase of DWA of Cyanobacteria population suggests that Cyanobacteria continued to grow (Figure 75, a). *Aphanizomenon* sp. and *Anabaena* sp. continued to dominate among the phytoplankton community (Figure 75, b). *Aphanizomenon* sp. accounted for 85% of the total Cyanobacterial biovolume (Figure 75, b), which made it a major part of the observed bloom. At the end of July 2011 Cyanobacteria population was reduced rapidly, indicating that the bloom collapsed. Later, the rest of the phytoplankton classes including diatoms, green

algae, and Cryptophyceae started to build up their population (Figure 75, a). The rapid drop of Cyanobacterial population coincided with the decrease of nutrient availability in the reservoir.

Similar to *Aphanizomenon* sp., and *Anabaena* sp., another Cyanobacterial genus, *Microcistys* sp., decreased with the decreasing nutrient availability on the surface in the reservoir. Conversely, although the nutrient availability was low, the biovolume of *Gomphosphaeria* sp. increased in the mid-summer when the reservoir was still stratified. Even though the aeration was resumed at the end of August, Cyanobacterial population did not increase at the same level as before stopping of aeration (Figure 75, a).

6.4.1. Effect of artificial aeration on vertical distribution of Cyanobacteria

Results from vertical biovolume distribution of Cyanobacteria show that, when aeration worked, Cyanobacteria were evenly distributed over the water column (Figure 80), indicating that the aeration dispersed them in deeper layers in the water column. However, when the aeration was stopped Cyanobacteria, as well as most of the phytoplankton tends to accumulate on the surface and at the thermocline.

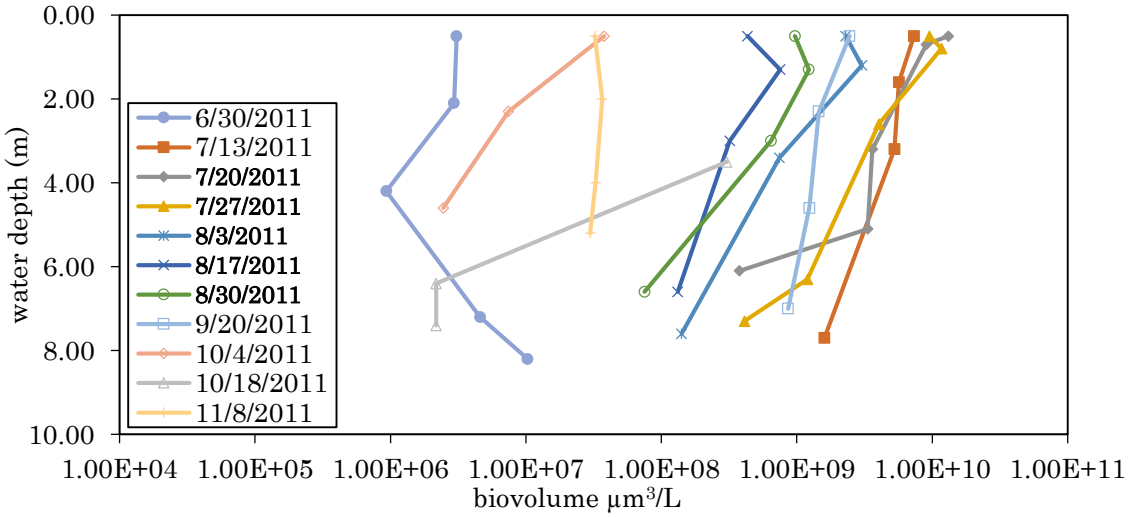

Figure 80. Vertical variation of Cyanobacterial biovolume at Site A (2011) without aeration in bolded dates in the legend

Walsby et al., (1997) observed a similar effect of mixing on *Aphanizomenon* sp. *Aphanizomenon* sp. was distributed deeper by the mixing event (a storm) but subsequently moved upwards and became more concentrated in the surface layers. That movement was the result of buoyancy regulation (Walsby et al., 1997). Buoyancy regulation is a common feature of Cyanobacteria species that provides a significantly important ecological advantage, which allows them to rise to upper water layer with enhanced levels of light (Walsby, 1997). In the same way, the accumulation of *Aphanizomenon* sp. in the surface layers in the HMD after stopping of the mixing was evidence for active buoyancy regulation of that genus

The increase of depth-weighted averaged biovolume of Cyanobacteria indicates that the population continued to grow (Figure 75, a) and that the increased biovolume of Cyanobacteria on the surface was not only result of accumulation on the surface. However, accumulations of phytoplankton in the surface layers coincided with the observed decrease of nutrient availability in the surface layers in the HMD. During the period without aeration, the nutrients accumulated on the bottom of the reservoir while the phytoplankton accumulated on the surface. Reduced mixing made nutrients less available for phytoplankton growth. At the same time, the reduced water column mixing and nutrient availability were coupled with changes in morphology of *Aphanizomenon* sp. and *Anabaena* sp. The aggregates were dispersed and populations consisted mostly of single filaments. The observed changes in genera morphology that coincided with the decreased nutrient availability indicated that the population was likely stressed. The water changed in color from light green to dark greenish-brown (Figure 81, a and b).

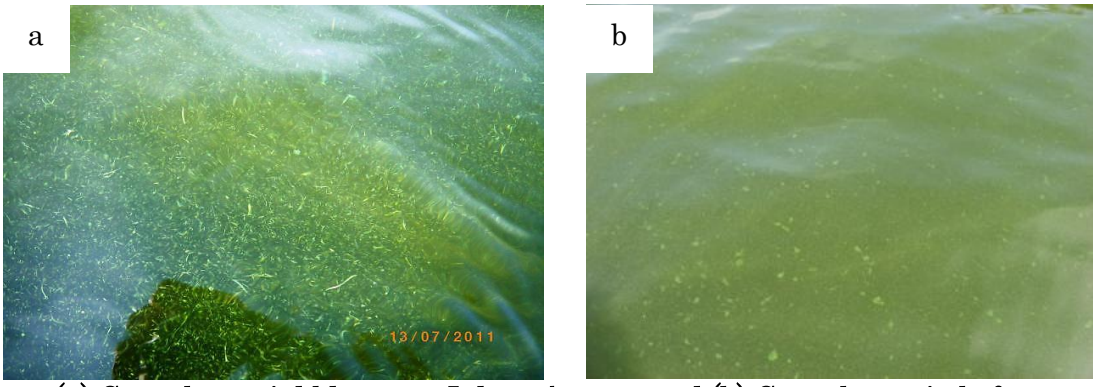

Figure 81. (a) Cyanobacterial bloom on July 13th, 2011 and (b) Cyanobacteria before collapse on July 27th, 2011

In 2011, a rapid and higher increase of DWA biovolumes of Cyanobacteria were observed at all sites in the reservoir when aeration was in operation (Table 28. CHAPTER 5). Two weeks after aeration was stopped Cyanobacteria bloom collapsed in the whole lake. Following the NDGFD report, our observations showed the consequences from the large Cyanobacterial die off: floating decaying biomass on surface, fish kill, and unpleasant aesthetics of the reservoir (Figure 82).

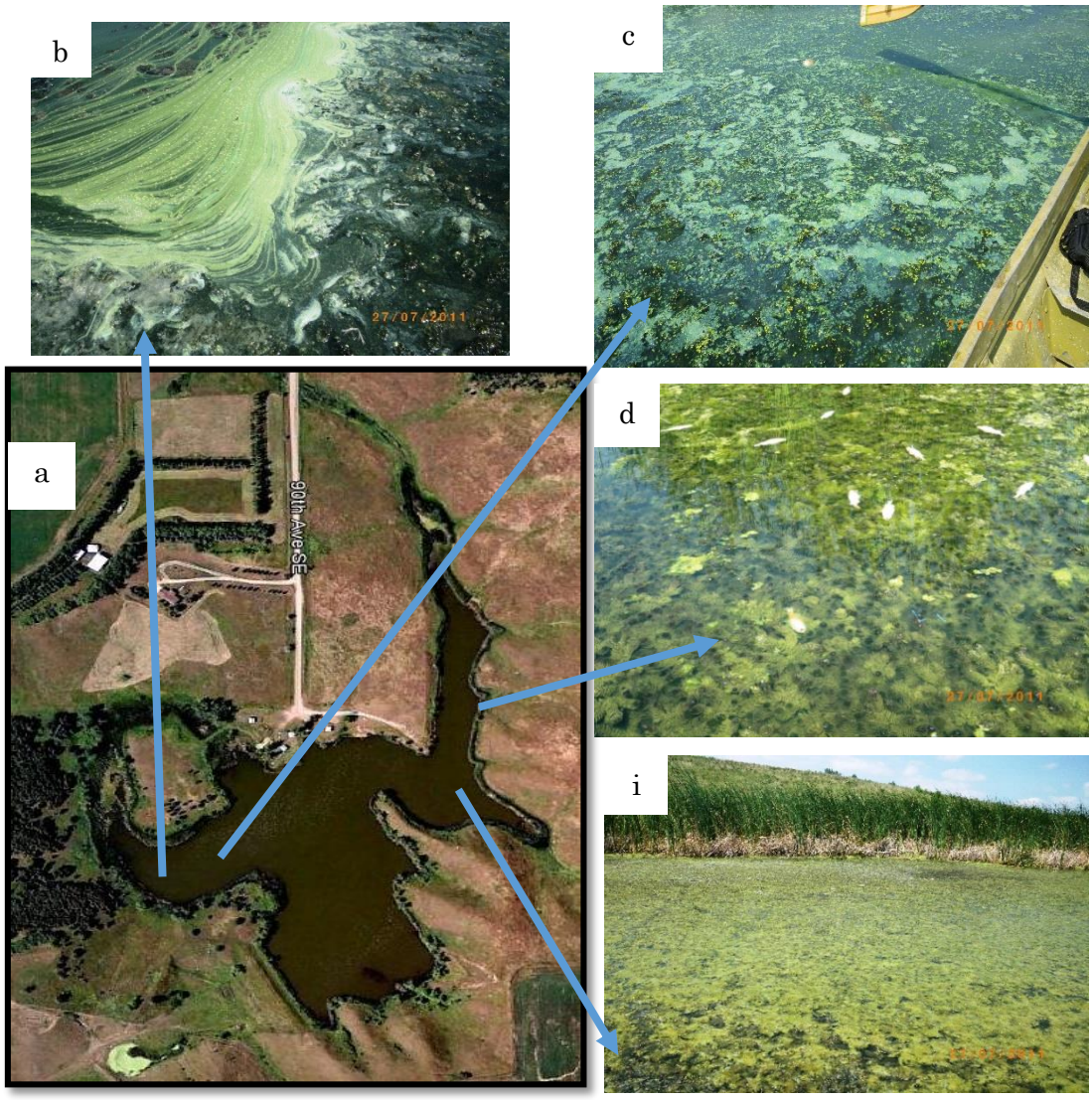

Figure 82. Heinrich-Martin Dam (a) HMD aerial photograph, (b) decaying phytoplankton biomass in the surface, (c) decaying macrophytes and phytoplankton biomass, (d) dead fish, and (i) shoreline close to Site D

6.5. Discussion

The aim of this Chapter as a part of the current study was to investigate effect of aeration on Cyanobacterial growth due to changing nutrient availability. Results of phytoplankton analyses in the HMD, which show increase of N_2-fixing Cyanobacteria when aeration was in operation, suggest that the artificial aeration was not able to suppress Cyanobacteria in the reservoir. Since the mixing generated from aeration increased

nutrient availability for the phytoplankton growth, the higher nutrient availability therefore should be considered as the most viable factor stimulating Cyanobacterial growth. In addition, the mixing of aeration resulted in a nearly uniform distribution of Cyanobacterial genera thorough the water column, thereby dispersing cells, filaments, and colonies deeper within the reservoir. This coupled with the equal distribution of nutrient in the water column, due to mixing, resulted in Cyanobacterial cells being exposed to the same nutrients availability over the whole water column.

The low N:P ratio in the HMD appears to be the most likely factor that could be used to explain Cyanobacteria dominance in the HMD. The ratio in the HMD was below 2, indicating a strong N-limitation. On the other hand, although a higher phytoplankton growth was measured, the gradual increase of P in the HMD indicates that the P was in an excess and was not a limiting factor for phytoplankton growth. Based on ability of certain cyanobacteria species to fix N_2, it has been widely accepted that eutrophic lakes and reservoirs with low N:P ratio will be dominated by N_2-fixing heterocystous Cyanobacteria (Smith, 1983; Smith et al., 1995; Downing et al., 2001; Havens et al., 2003; Schindler et al., 2008). Both dominant Cyanobacterial species identified in the HMD, *Aphanizomenon* sp. and *Anabaena* sp., have ability to reduce of N_2 to NH_4^+ in presence of nitrogenize, which provides them ability to grow successfully in nitrogen-limited condition (Brezonik, 1973; LaRoche & Breitbarth, 2005). Since the HMD was nitrogen limited, the N_2-fixer growth requirements were likely met by N_2-fixation.

Nevertheless, the paradigm that the Cyanobacteria depended on the N_2-fixation to dominate in the N-limited environment is questionable. Some studies showed N-limitation does not necessary mean that fixation was taking place (Ferber et al., 2004; Wood et al., 2010). There is evidence that the Cyanobacteria N_2-fixation is not the only mechanism that

could explain their competitive dominance in nitrogen-limited lakes. For instance, in the study conducted by Ferber et al., (2004), although Cyanobacteria accounted for 81-98% of phytoplankton biomass during the summer's months, the N-fixation contributed 2% of the N-required. Instead, as found by other studies, Cyanobacteria obtained most of the N required through ammonia uptake. Leonardson (1984), Degerholm et al. (2006), and De Nobel et al. (1997) reported similar findings.

In another study, Wood et al. (2010) observed that at low N:P ratio the higher annual heterocyst frequency reached maximum before the peak in annual biomass. These observations indicate that at low N concentrations, N-fixation likely brought the *Anabaena* sp. to dominate. Decrease of heterocyst's during increase in the biomass suggest that likely *Anabaena* switched to energetically cheaper N source (ammonium) when the N in water increased. The reason for this switch involves energy spent for different N sources. The N_2-fixation itself is an expensive metabolic process (16 molecules ATP and 8 electrons for each N_2 fixed) (Bergman et al., 1997), while assimilation of external nitrite across the cell membrane before reduction to ammonium requires 1 ATP (Flores, 2005; Stal, 2009). Cyanobacteria have lower N_2 fixation rates than DIN uptake rates (Presing et al., 1996; Ferber et al, 2004, Burford et al., 2006). On the other hand, it is generally agreed that ammonium is the most easily assimilated form of nitrogen, followed by nitrate and nitrite, followed by atmospheric nitrogen (Oliver & Ganf, 2000; Sober et al., 2003, Ferber et al., 2004; Flores & Herrero, 2005). Therefore, even in lower concentrations as long as nitrogen is presented, Cyanobacteria would prefer energetically cheaper nitrogen.

Diatoms and dinoflagellates also prefer the ammonium uptake as a lower energetically level consuming energy source (Reynolds, 2006). Cyanobacteria, however, has lower half–saturation constant than the other phytoplankton species and can dominate at

low nitrogen concentrations (Sommer, 1986; Smith, 1985; Halterman & Toetz, 1984). Therefore, concentrations of nitrogen and the kinetic of nutrient uptake in addition to the N_2-fixation will be of significance to explain Cyanobacteria dominance. In addition, among N2-fixing Cyanobacteria, also identified in the HMD, *Apnanizomenon* sp. had a lower half-saturation constant than Anabaena sp. (De Nobel et al., 1998). Moreover, Halterman & Toetz (1984) found *Apnanizomenon flos-aquae* to have the lowest half–saturation constant for nitrate uptake of all 18 phytoplankton species. In addition to the slower growth rates of Cyanobacteria (Meeks et al., 1983) in comparison with diatoms (Litchman, 2000) and green algae (Varis, 1993; Lurling, 2013), low half–saturation constant for nitrogen excludes other species in the competition for limited nitrogen (Tilman, 1982; Grover, 1997).

The observed changes in morphology of Cyanobacteria are also important evidence of that higher nutrient availability, due to aeration, can support Cyanobacterial growth. The advantage of forming big "grass-blade" aggregates not only provide faster migration (Walsby et al. 1995) but also decrease grazing of zooplankton. Reduced grazing would increase their competition over other algae, since grazing pressure is directed toward smaller species (Cyr & Pace, 1993). Forming large colonies may have, however, a negative effect on cyanobacterial growth. Forming aggregates results in decreases area to volume ratio, which usually reduces nutrients uptake (Stal & Walsby, 2000). However, occurrence of aggregates when the reservoir was artificially mixed and the nutrient availability in the reservoir was higher suggests that the *Aphanizomenon* sp. and *Anabaena* sp. are not nutrient limited.

However, when aeration was stopped and subsequent mixing of water resulted, TDIN and SRP accumulated on the bottom of the reservoir. Although released in higher concentrations, nutrients were less available for the growth. The switch from mixing to

stable condition resulted in a subsequent movement of N_2-fixing Cyanobacteria upwards and accumulation in the surface layers, where the nutrient availability was already limited. In addition to accumulation of *Aphanizomenon* sp. and *Anabaena* sp. in the surface layers, observed change in morphology also indicated change in nutrient availability. Observed separation of aggregates into single filaments had positive and negative impacts on both genera. Single filaments increased the surface area to volume ratio, thereby increasing nutrient uptake (Foy, 1980). One the other hand, single filaments have been demonstrated to settle slower than a colony (Walsby et al. 1995), which in addition to buoyancy regulations allowed them to remain longer in the surface, where the light intensity is higher. However, staying longer in the surface layers where the nutrient availability might not be beneficial for N_2-fixing species because high irradiance may decrease the rate of gas vehicle production (Booker & Walsby, 1981; Konopka, 1982). In addition, nutrient limitation in lake and reservoirs as demonstrated in several experiments could cause buoyancy losses by Cyanobacterial species (Reynolds & Walsby, 1975; Konopka, 1982; Brookes et al., 1999).

Although at a slow rate, Cyanobacteria increased its population because of availability either to fix N_2 or to grow at relatively low N concentrations, Cyanobacterial genera appear to be "poor competitors" for phosphorus (Smith, 1985). Cyanobacterial N_2-fixing species were found to have the highest half-saturation constant for P uptake in comparison with diatoms (Tilman et al., 1982), green algae (Sommer. 1986; Shafic, 1991; Spijkeman & Coesel, 1996), and dinoflagellates (Berman & Dumbinsky, 1985), which makes them less competitive for P among phytoplankton classes. In addition, *Aphanizomenon* sp. was found to have a higher half-saturation constant for P in comparison with the other N_2-fixing genus Anabaena sp. (De Nobel et al., 1997), which

makes *Aphanizomenon* sp. a worse competitor when P is limited. The rapid decrease of Cyanobacterial population two weeks after the aeration was stopped coupled with the decrease of nutrient availability confirms that the P became limited for Cyanobacteria.

Cyanobacteria also can store P as polyphosphate reserves (Simon, 1987) when P is in excess (Sandgreen, 1991), which could explain their continuous growth for short period in HMD when P availability decreased. Although it P-storage enables Cyanobacteria to perform a few cell divisions and to increase in biomass (Collier & Grossman, 1992; Chorus & Mur, 1999), prolonged P limitation usually result in decreased growth, reduced P cell content, and suppressed heterocyst formation (Chu et al, 2007). Decreased heterocysts result in a reduction in N_2-fixation, which decrease cellular N content (Thompson et al., 1994; Degerholm et al., 2006). On the other hand, the N-limitation cause loss of buoyancy by restricting production of proteins (Layzell et al., 1985; Thompson et al., 1994; Chu et al, 2007). Therefore, prolonged P-limitation would cause Cyanobacteria to lose both of the most advantageous abilities: N_2-fiaxation and buoyancy regulation. Decreased P cellular content also results in less Chl-*a* content in *Apanizomenon* sp. (Degerholm et al., 2006), changing coloration of Cyanobacterial cells (Sakamoto & Bryant, 1998). Additional experiments showed that the combination of nitrogen fixation process and P-limitation does not favor *Aphanizomenon* sp. (De Nobel et al., 1997). After all, the observed change in morphology in Cyanobacteria, combined with decreased nutrient availability, indicates that the organism was stressed due to P-limitation. Ability of nitrogen N_2-fixation and to grow at low N concentrations helps Cyanobacteria to balance N-requirements in N-limited freshwater ecosystems, making P the key controlling nutrient responsible for the Cyanophyceae growth.

6.6. Conclusions

In addition to low the N:P ratio, availability of N and P are important for the Cyanobacterial growth because Cyanobacteria:

- can grow efficiently under low nitrogen concentrations, because
    - relatively fast growth rate of Cyanobacteria at low TDIN concentrations
    - some Cyanobacteria species can fix N_2 from atmosphere
- can grow in P rich environment

Rather than reducing Cyanobacteria, limited N limitation in lakes in addition to increased P availability, due to artificial aeration, will favor Cyanobacteria growth.

CHAPTER 7. GENERAL CONCLUSIONS

The purpose of current study was to evaluate effects of artificial aeration on sediment nutrient, and impact of changes in nutrients on algal growth and phytoplankton community structure. Based on the results, the internal loading or sediment release of N and P is identified as the major nutrient source in the reservoir. Aeration was found effective on reducing sediment nutrient release, especially release of orthophosphate. Phosphorous flux from sediment was reduced by nearly 50% under aerated conditions. This is mostly likely due to the increase of DO concentration (higher redox potential) at water-sediment interface that inhibited the release of a metal bound phosphate. Although aeration was found effective in reducing sediment nutrient release (TP) by nearly 50%, it was not able to eliminate TP because release of P, as well as N, by biological degradation of organic sediment matter continued. Aerobic condition might have resulted in higher biological degradation rates and thus caused increase of sediment nutrient release.

Results of this research also show that after aeration was turned off a weak thermal stratification was reestablished in a short period, which effectively limited vertical mixing, and mass transfer between water surface and the reservoir bottom. Although more nutrients were released under this condition, most of released N and P were trapped in the bottom layer and were not available for supporting phytoplankton growth. In contrast, well mixed chemical ingredients and mixing induced vertical distribution of phytoplankton make nutrients more available for phytoplankton growth under aerated condition, which was confirmed by higher Chl-*a* concentrations and phytoplankton biovolume.

Analysis of biovolume data also show that the mixing and higher nutrient availability due to aeration prolonged higher growth of diatoms, dinoflagellates, and Cyanobacteria in summer months when compared to other natural lakes. Based on the

analysis of concentration data, more nutrients are available for phytoplankton growth due to mixing under aerated condition. In addition, the study showed that the HMD has very low N:P ratio, indicating nitrogen is the limiting nutrient. Although both N and P were added continuously to the water column and were able to support higher growth of some of the genera identified in the HMD, the strong N-limitation in the reservoir is a growth-limiting factor, which controls the growth and shift of genera in their seasonal succession.

Many studies, including this one, have found that low N:P ratio favors the growth of Cyanobacteria because some Cyanobacteria species have capabilities to fix N_2. The bloom of N_2-fixing species in the HMD observed during aeration suggest that aeration did not inhibit Cyanobacterial growth as suggested by other studies. In contrast, higher nutrient availability under aerated conditions, and relatively low N concentration and high P concentration created favorable condition and competitive edges for the growth of Cyanobacteria. In general, Cyanobacteria have higher half saturation constant for phosphorus and low half saturation constant for nitrogen, and some Cyanobacterial species are able to fix N_2.

Based on the results of this study, it is concluded that the artificial aeration could not reduce the phytoplankton growth in lakes and reservoirs with organic rich sediments, because phosphorus is continuously released from biological degradation of organic matter, and mixing from aeration makes nutrients more available for phytoplankton growth.

More study is needed to determine the rates of sediment nutrient release, and to reveal chemical and biological mechanisms that control the seasonal cycle of phosphorus. Controlled experiment with extended period should be designed and conducted to simulate P release from sediments under aerobic and anaerobic condition to study the kinetics of metal bound phosphorus dissolution and biologically released phosphorus.

It is important for lake and reservoir managers to develop a better understanding of the internal sediment release and its impact on lake nutrient cycles to improve water quality. We believe that the research on the effect of artificial aeration on nutrient release and availability described and discussed in this dissertation will assist managers in choosing the right restoration techniques.

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APPENDIX A. FIELD MONITORING AND SAMPLING RESULTS

The data included in this appendix cover sampling periods in 2010 and 2011.

A1. Field Monitoring and Sampling Results 2010

A1.1. Field monitoring and sampling results, Site A (2010)

Table A1. Sampling depths (m), Site A (2010)

date (mo/day/yr)	water depth (m)				
	Surface	Secchi depth	2 × Secchi depth	1.5m from the bottom	maximum depth
6/4/2010	0.50	2.30	3.70	5.20	7.60
6/18/2010	0.50	1.00	2.00	4.30	5.80
7/9/2010	0.50	1.60	3.20	7.60	8.47
7/23/2010	0.50	1.30	2.60	5.30	7.30
8/6/2010	0.50	1.70	3.40	4.30	7.30
8/20/2010	0.50	1.20	2.40	5.60	7.00
9/3/2010	0.50	1.30	2.60	4.40	5.60
9/17/2010	0.50	1.30	2.60	5.10	6.10
10/10/2010	0.50	1.80	3.60	5.80	7.00
10/15/2010	0.50	2.50			8.80

Table A2. Water temperature (°C), Site A (2010)

date (mo/day/yr)	water depth (m)										
	0.5	1	2	3	4	5	6	7	8	9	10
6/4/2010	20.53	20.12	19.89	19.75	19.66	19.55	19.22	19.08	18.91	18.87	18.84
6/18/2010	19.81	19.85	19.85	19.85	19.79	19.82	19.82				
7/9/2010	25.15	24.52	24.05	23.92	23.85	23.80	23.75	23.67	23.57	23.57*	
7/23/2010	24.33	24.22	24.16	24.10	24.06	24.03	23.97	23.96	23.62	23.41	
8/6/2010	24.92	24.75	24.44	24.50	24.39	24.45	24.38	24.39	24.39		
8/20/2010	22.52	22.50	22.49	22.48	22.47	22.47	22.46	22.43			
9/3/2010	20.86	20.71	20.64	20.60	20.54	20.52	20.50*				
9/17/2010	16.88	16.69	16.62	16.58	16.57	16.56	16.58				
10/10/2010	15.37	15.25	15.23	15.21	15.19	15.18	15.01	14.16*			
10/15/2010	13.61	13.60	13.59	13.57	13.58	13.57	13.54	13.55	13.41	13.39*	

Note: *values indicate bottom reading at depth less than the depth of the column

Table A3. Dissolved Oxygen (mg/L), Site A (2010)

date (mo/day/yr)	water depth (m)										
	0.5	1	2	3	4	5	6	7	8	9	10
6/4/2010	8.69	8.70	8.56	8.49	8.5	8.18	6.42	5.95	5.17	3.14	1.82
6/18/2010	7.57	7.24	7.11	7.04	6.96	6.89	6.82				
7/9/2010	6.39	6.31	5.67	4.64	4.34	4.3	4.16	3.65	2.38	2.38*	
7/23/2010	6.59	6.17	5.95	5.6	5.25	5.09	4.81	4.82	2.67	0.70	
8/6/2010	5.97	5.51	4.16	3.92	3.72	3.87	3.97	4.24	4.19		
8/20/2010	5.57	5.21	4.87	4.64	4.49	4.44	4.38	4.15			
9/3/2010	7.34	7.16	7.01	6.82	6.52	6.43	6.33*				
9/17/2010	8.77	8.35	8.01	7.69	7.57	7.53	0.79				
10/10/2010	10.61	10.42	10.3	10.02	9.74	9.69	8.72	2.19*			
10/15/2010	6.48	6.55	6.5	6.37	6.28	6.22	6.17	6.14	5.76	5.51*	

Note: * values indicate bottom reading at depth less than the depth of the column

Table A4. Conductivity (mS/cm), Site A (2010)

date (mo/day/yr)	water depth (m)										
	0.5	1	2	3	4	5	6	7	8	9	10
6/4/2010	638	640	640	640	640	642	644	645	649		
6/18/2010	668	669	670	670	670	670	670				
7/9/2010	701	705	709	710	710	709	710	711	714	714*	
7/23/2010	719	721	722	721	721	721	722	722	731		
8/6/2010	750	752	755	756	756	758	756	755	755		
8/20/2010	731	733	733	734	734	734	734	734			
9/3/2010	753	755	758	758	758	760	760*				
9/17/2010	766	768	769	770	770	770	735				
10/1/2010	777	779	779	780	780	781	782	790			
10/15/2010	810	810	812	813	813	813	813	813	814		

Note: * values indicate bottom reading at depth less than the depth of the column

Table A5. Chlorophyll-a (µg/L) ± STD (replicates), Site A (2010)

date (mon/day/yr)	water depth (m)			
	at the Surface	at the Secchi depth*	at the 2 × Secchi depth*	at the 1.50m from the bottom*
6/4/2010	14.43±0.53	12.30±6.30	11.76±1.07	8.20±3.13
6/18/2010	32.88±0.76	32.88±11.72	24.59±2.27	26.46±1.13
7/9/2010	17.64	1.60	6.42	4.28
7/23/2010	43.84	75.91	54.53	41.16
8/6/2010	36.89	71.64	44.91	24.59
8/20/2010	33.68±1.51	33.15	34.48±3.78	32.08
9/3/2010	59.34	58.27	55.60	49.72
9/17/2010	56.13	56.67	51.86	50.25
10/1/2010	28.87	33.15	28.33	27.53
10/15/2010	9.09	7.48	9.09	8.55

Note: *depths varied each day and measurements can be found in Table A1.

A1.2. Field monitoring and sampling results, Site B (2010).

Table A6. Sampling depths (m), Site B (2010)

date (mo/day/yr)	water depth (m)				
	Surface	Secchi depth	2 × Secchi depth	1.5 from the bottom	maximum depth
6/4/2010	0.5	1.85	3.7		5.7
6/18/2010	0.5	1.0	2.0		8.5
7/9/2010	0.5	1.6	3.2		8.1
7/23/2010	0.5	1.3	2.6	5.3	5.8
8/6/2010	0.5	1.7	3.4	4.3	4.8
8/20/2010	0.5	1.2	2.4	5.6	6.1
9/3/2010	0.5	1.2	2.4	4.4	4.9
9/17/2010	0.5	1.3	2.6	5.1	5.6
10/10/2010	0.5	1.8	3.8	5.5	6.3
10/15/2010	0.5	2.5	3.6		8.8

Table A7. Water temperature (°C), Site B (2010)

date (mo/day/yr)	water depth (m)									
	0.5	1	2	3	4	5	6	7	8	9
6/4/2010	20.57	20.31	20.22	20.18	20.14	19.44	19.14*			
6/18/2010	20.19	20.13	20.11	20.08	20.07	20.06	20.04	20.03	20.03	19.81
7/9/2010	25.23	24.20	23.87	23.78	23.67	23.65	23.61	23.52	23.49	
7/23/2010	23.96	24.00	24.01	23.94	23.94	23.91	23.89	23.96*		
8/6/2010	24.6	24.51	24.46	24.43	24.41	24.38*				
8/20/2010	22.72	22.56	22.51	22.49	22.48	22.48	22.47			
9/3/2010	20.4	20.46	20.47	20.48	20.49	20.46				
9/17/2010	16.63	16.65	16.64	16.54	16.51	16.47	16.46			
10/1/2010	15.22	15.21	15.19	15.18	15.17	15.05	14.71*			
10/15/2010	13.62	13.64	13.64	13.64	13.64					

Note: * values indicate bottom reading at depth less than the depth of the column

Table A8. Dissolved oxygen (mg/L), Site B (2010)

date (mo/day/yr)	water depth (m)									
	0.5	1	2	3	4	5	6	7	8	9
6/4/2010	9.28	9.28	9.28	9.25	9.20	7.72	3.76*			
6/18/2010	8.20	8.04	8.03	7.92	7.86	7.86	7.81	7.80	7.80	2.82
7/9/2010	7.19	6.06	5.39	5.20	4.42	4.15	3.97	2.62	1.97	
7/23/2010	6.57	6.33	6.17	5.03	5.19	4.66	4.5	0.74*		
8/6/2010	4.82	4.45	3.96	3.90	3.60	2.14*				
8/20/2010	5.25	4.57	4.31	4.04	3.91	3.84	2.47			
9/3/2010	7.83	7.67	7.57	7.51	7.50	5.09				
9/17/2010	8.54	8.22	8.12	7.56	7.19	6.70	6.59*			
10/1/2010	10.76	10.60	10.35	10.29	10.17	8.64	0.32*			
10/15/2010	6.62	6.62	6.63	6.62	4.38					

Note: * values indicate bottom reading at depth less than the depth of the column

Table A9. Conductivity (mS/cm), Site B (2010)

date (mo/day/yr)	water depth (m)									
	0.5	1	2	3	4	5	6	7	8	9
6/4/2010	614	617	623	637	639	640	645			
6/18/2010	669	669	669	670	670	670	670	670	670	706
7/9/2010	708	709	709	708	710	710	711	711	712	
7/23/2010	719	719	720	721	721	721	722			
8/6/2010	754	754	755	756	757	757*				
8/20/2010	731	733	733	734	734	734	734			
9/3/2010	760	759	759	759	759	760				
9/17/2010	768	768	769	770	770	771	771			
10/1/2010	779	779	780	779	780	781	788			
10/15/2010	812	812	813	813	813					

Note: * values indicate bottom reading at depth less than the depth of the column

Table A10. Chlorophyll-*a* (μm/L) and STD (replicates), Site B (2010)

date (mo/day/yr)	water depth (average ± STD)			
	at the surface	at the Secchi depth*	at the 2 × Secchi depth*	at the 0.5m from the bottom
6/4/2010	13.01±2.53	12.30±3.25	13.37±4.90	
6/18/2010	30.21±2.65	26.46±1.89	30.47±3.02	
7/9/2010	5.88	5.35	8.55	
7/23/2010	64.69	59.34	61.48	23.52
8/6/2010	70.57	66.83	39.03	22.45
8/20/2010	61.81±0.00	61.81	42.32	22.99
9/3/2010	70.57	73.77	74.84	69.50
9/17/2010	57.74	66.83	61.48	29.4
10/1/2010	37.96	34.21	27.8	10.16
10/15/2010	5.35	9.62	N/A	N/A

Note: *depth varied each day and measurements are given in Table A6.

Table A11. Ammonium nitrogen (mg/L), Site B (2010)

date (mo/day/yr)	water depth (m)			
	at the surface	at the Secchi depth*	at the 2 × Secchi depth*	at the 0.5m from the bottom
6/4/2010	0.01	0.01	0.01	0.01
6/18/2010	0.03	0.03	0.02	0.03
7/9/2010	0.00	0.04	0.00	0.02
7/23/2010	0.11	0.05	0.17	0.13
8/6/2010	0.04	0.00	0.02	0.03
8/20/2010	0.04	0.05	0.06	0.07
9/3/2010	0.00	0.00	0.00	0.00
9/17/2010	0.00	0.01	0.00	0.01
10/1/2010	0.00	0.00	0.01	0.00
10/15/2010	0.02	0.02	0.02	

Note: *depth varied each day and measurements are given in Table A6.

Table A12. Nitrate-nitrogen (mg/L), Site B (2010)

date (mo/day/yr)	water depth			
	at the surface	at the Secchi depth*	at the 2 × Secchi depth*	at the 0.5m from the bottom
6/4/2010				
6/18/2010	0.15	0.12	0.10	0.11
7/9/2010	0.16	0.17	0.13	0.13
7/23/2010	0.10	0.10	0.09	0.09
8/6/2010	0.16	0.13	0.10	0.10
8/20/2010	0.09	0.09	0.11	0.09
9/3/2010	0.09	0.10	0.10	0.09
9/17/2010	0.15	0.15	0.15	0.15
10/1/2010	0.10	0.09	0.09	0.09
10/15/2010	0.13	0.13	0.12	

Note: *depth varied each day and measurements are given in Table A6

Table A13. Nitrite-nitrogen (mg/L), Site B (2010)

date (mo/day/yr)	water depth			
	at the surface	at the Secchi depth*	at the 2 × Secchi depth*	at the 0.5m from the bottom
6/4/2010	0.00	0.00	0.00	0.00
6/18/2010	0.00	0.00	0.00	0.00
7/9/2010	0.00	0.00	0.00	0.00
7/23/2010	0.00	0.00	0.00	0.00
8/6/2010	0.00	0.00	0.00	0.00
8/20/2010	0.00	0.00	0.00	0.00
9/3/2010	0.00	0.00	0.00	0.00
9/17/2010	0.00	0.00	0.00	0.00
10/1/2010	0.00	0.00	0.00	0.00
10/15/2010	0.00	0.02	0.02	

Note: *depth varied each day and measurements are given in Table A6.

Table A14. Total nitrogen (mg/L), Site B (2010)

date (mo/day/yr)	water depth			
	at the Surface	at the Secchi depth*	at the 2 × Secchi depth*	at the 0.5m from the bottom
6/4/2010				
6/18/2010	1.31	1.54	1.55	1.51
7/9/2010	2.23	1.73	3.63	2.51
7/23/2010	1.99	2.07	1.74	1.49
8/6/2010	1.43	2.36	1.99	1.49
8/20/2010	1.24	1.23	1.28	1.24
9/3/2010	1.67	1.97	1.70	1.60
9/17/2010	2.71	2.44	2.67	2.69
10/1/2010	2.11	1.86	1.84	1.67
10/15/2010	2.40	2.53	2.53	

Note: *depth varied each day and measurements are given in Table A6.

Table A15. Soluble reactive phosphorus (mg/L), Site B (2010)

date (mo/day/yr)	water depth			
	at the surface	at the Secchi depth*	at the 2 × Secchi depth*	at the 0.5m from the bottom
6/4/2010	0.07	0.05	0.06	0.07
6/18/2010	0.09	0.11	0.11	0.11
7/9/2010	0.11	0.12	0.12	0.14
7/23/2010	0.13	0.12	0.13	0.13
8/6/2010	0.18	0.18	0.17	0.16
8/20/2010	0.15	0.15	0.16	0.16
9/3/2010	0.12	0.12	0.13	0.13
9/17/2010	0.10	0.10	0.09	0.09
10/1/2010	0.07	0.06	0.07	0.07
10/15/2010	0.06	0.06	0.06	

Note: *depth vary each day and measurements are given in Table A6.

Table A16. Total phosphorus (TP) (mg/L), Site B (2010)

date mm/dd/yy	water depth			
	at the surface	at the Secchi depth*	at the 2 × Secchi depth*	at the 0.5m from the bottom
6/4/2010	0.11	0.13	0.11	0.12
6/18/2010	0.15	0.15	0.15	0.14
7/9/2010	0.17	0.18	0.17	0.16
7/23/2010	0.20	0.22	0.23	0.19
8/6/2010	0.27	0.27	0.23	0.23
8/20/2010	0.27	0.26	0.25	0.22
9/3/2010	0.25	0.25	0.25	0.25
9/17/2010	0.18	0.17	0.20	0.17
10/1/2010	0.13	0.14	0.13	0.14
10/15/2010	0.10	0.13		

Note: *depth vary each day and measurements are given in Table A6.

A1.3. Field monitoring and sampling results, Site C (2010).

Table A17. Sampling depths (°C), Site C (2010)

date (mo/day/yr)	water depth (m)			
	at the surface	at the Secchi depth	at the1.5m from the bottom	maximum depth
6/4/2010	0.50	2.50	3.80	4.30
6/18/2010	0.50	0.90	2.40	2.70
7/9/2010	0.50	1.40	3.10	3.60
7/23/2010	0.50	1.20		3.50
8/6/2010	0.50	1.10	3.02	3.70
8/20/2010	0.50	1.20	3.60	4.10
9/3/2010	0.50	1.80	3.50	4.00
9/17/2010	0.50	1.20	3.30	3.80
10/10/2010	0.50	1.80	2.70	3.20
10/15/2010				

Table A18. Water temperature (°C), Site C (2010)

date mo/day/yr	water depth (m)					
	0.5	1	2	3	4	5
6/4/2010	20.71	20.41	19.79	19.61	19.50	19.25*
6/18/2010	20.37	20.21	20.15	20.04		
7/9/2010	25.27	25.01	24.47	24.18	24.07*	
7/23/2010	23.86	24.07	23.99	23.96	23.94*	
8/6/2010	25.52	24.84	24.54	24.47	24.39*	
8/20/2010	22.65	22.55	22.51	22.46	22.27	
9/3/2010	20.51	20.56	20.59	20.57	20.04	
9/17/2010	16.75	16.80	16.76	16.52	16.48*	
10/1/2010	15.41	15.37	15.36	15.35		
10/15/2010						

Note: * values indicate bottom reading at depth less than the depth of the column

Table A19. Dissolved Oxygen (mg/L), Site C (2010)

date mo/day/yr	water depth (m)					
	0.50	1.00	2.00	3.00	4.00	5.00
6/4/2010	9.13	9.18	8.83	8.49	7.86	2.60*
6/18/2010	7.86	7.66	7.62	7.25		
7/9/2010	7.79	7.68	6.63	5.58	4.56*	
7/23/2010	7.79	7.62	6.24	6.17	5.84*	
8/6/2010	7.38	7.23	5.08	4.98	4.71*	
8/20/2010	5.74	5.17	4.68	4.61	3.62	
9/3/2010	8.25	8.18	8.03	7.83	7.31	
9/17/2010	9.41	9.24	8.88	7.34	7.34*	
10/1/2010	11.24	11.09	10.98	10.34*		
10/15/2010						

Note: * values indicate bottom reading at depth less than the depth of the column

Table A20. Conductivity (mS/cm), Site C (2010)

date mo/day/yr	water depth (m)					
	0.5	1	2	3	4	5
6/4/2010	639	640	641	642	643	647*
6/18/2010	669	697	670	671		
7/9/2010	698	704	704	704	706*	
7/23/2010	718	716	719	719	719*	
8/6/2010	751	749	753	753	755*	
8/20/2010	733	732	733	732	733	
9/3/2010	756	756	756	758	758	
9/17/2010	769	768	768	770	770	
10/1/2010	779	780	780	780		
10/15/2010						

Note: * values indicate bottom reading at depth less than the depth of the column

Table A21. Chlorophyll-*a* (µg/L) and STD (replicates), Site C (2010)

date mo/day/yr	water depth		
	at the Surface	at the Secchi depth	at 0.5m from the bottom
6/4/2010	12.47±2.74	14.79±0.31	16.04±3.51
6/18/2010	24.06±1.51	23.52±0.76	21.12±0.38
7/9/2010	31.54	25.66	5.346
7/23/2010	98.37	97.83	
8/6/2010	55.60	35.28	62.01
8/20/2010	64.69±0.00	82.33	40.09
9/3/2010	63.35	54.53	53.46
9/17/2010	72.71	54.53	53.46
10/1/2010	34.21	19.78	50.78
10/15/2010			

Note: *depth vary each day and measurements are given in Table A17.

A1.4. Field monitoring and sampling results, Site D (2010)

Table A22. Sampling depths (m), Site D (2010)

date (mo/day/yr)	water depth (m)			
	at the surface	at the Secchi depth	at the 1.5m from the bottom	maximum depth
6/4/2010	0.50	2.30	4.20	4.70
6/18/2010	0.50	1.20	4.20	4.70
7/9/2010	0.50	1.80	3.70	4.20
7/23/2010	0.50	1.00		4.40
8/6/2010	0.50	1.30	3.10	3.60
8/20/2010	0.50	0.90	2.8	3.30
9/3/2010	0.50	1.40	3.10	3.30
9/17/2010	0.50	1.30	4.00	4.50
10/10/2010	0.50	1.80	3.90	4.40
10/15/2010				

Table A23. Water temperature (°C), Site D (2010)

date mo/day/yr	water depth (m)						
	0.5	1	2	3	4	5	6
6/4/2010	20.73	20.67	20.57	19.80	19.41	19.30*	18.87*
6/18/2010	19.87	19.97	19.97	19.96	19.94	19.92*	
7/9/2010	26.58	24.68	24.27	24.03	23.81		
7/23/2010	24.18	24.07	24.02	23.84	23.6	22.98*	
8/6/2010	24.88	24.82	24.58	24.42	24.35*		
8/20/2010	22.57	22.57	22.5	22.45			
9/3/2010	20.37	20.44	20.45	20.38	20.23	19.9*	
9/17/2010	16.47	16.68	16.70	16.65	16.56	16.50*	
10/1/2010	15.50	15.65	15.37	15.25	14.96*		
10/15/2010							

Note: * values indicate bottom reading at depth less than the depth of the column

Table A24. Dissolved Oxygen (mg/L), Site D (2010)

date mo/day/yr	water depth (m)						
	0.5	1	2	3	4	5	6
6/4/2010	9.57	9.60	9.60	9.21	8.81	8.24	4.60*
6/18/2010	8.07	7.88	7.88	7.77	7.75	7.38*	
7/9/2010	8.55	7.12	5.77	4.93	4.83		
7/23/2010	8.62	6.71	6.07	5.76	5.46	5.64*	
8/6/2010	5.92	5.88	4.33	3.75	4.56*		
8/20/2010	5.8	4.8	4.24	4.15			
9/3/2010	8.51	8.41	8.26	8.16	7.73	6.31*	
9/17/2010	8.86	8.81	8.93	7.91	8.01	7.56*	
10/1/2010	11.70	11.45	10.51	9.87	7.13*		
10/15/2010							

Note: * values indicate bottom reading at depth less than the depth of the column

Table A25. Conductivity (mS/cm), Site D (2010)

date mo/day/yr	water depth (m)						
	0.5	1	2	3	4	5	6
6/4/2010	643	642	643	644	646	650	672*
6/18/2010	674	674	674	675	675	676*	
7/9/2010	708	706	708	710	712		
7/23/2010	716	718	719	718	722	741*	
8/6/2010	750	751	755	756	755*		
8/20/2010	728	733	733	733			
9/3/2010	760	759	758	759	760	766*	
9/17/2010	772	770	770	771	774	779*	
10/1/2010	780	780	783	785	788		
10/15/2010							

Note: * values indicate bottom reading at depth less than the depth of the column

Table A26. Chlorophyll-*a* (μg/L) and STD (replicates), Site D (2010)

date mo/day/yr	water depth		
	at the surface	at the Secchi depth*	at the 1.5m from the bottom
6/4/2010	12.83±3.74	18.53±0.31	17.64±3.70
6/18/2010	35.28	24.32±1.13	28.32
7/9/2010	16.57	16.04	6.95
7/23/2010	159.31	158.24	
8/6/2010	59.88	67.89	33.68
8/20/2010	109.33±2.65	113.34	60.41
9/3/2010	77.52	82.86	67.89
9/17/2010	68.43	61.48	47.58
10/1/2010	34.21	19.78	50.78
10/15/2010			

Note: *depth vary each day and measurements are given in Table A22

A2. Field Monitoring and Sampling Results, 2011

A2.1. Field monitoring and sampling results, Site A (2011)

Table A27. Sampling depths (m), Site A (2011)

date (mo/day/yr)	water depth						
	Surface	Secchi depth	2 × Secchi depth	thermocline	1.5m from the bottom	0.5m from the bottom	maximum depth
6/30/2011	0.50	2.10	4.20		7.20	8.20	8.70
7/13/2011	0.50	1.60	3.20		7.70		9.20
7/20/2011	0.50	0.70		3.00	5.10	6.10	6.60
7/27/2011	0.50	0.80		4.00	6.30		7.80
8/3/2011	0.50	1.20		3.00		7.70	9.09
8/17/2011	0.50	1.30		3.00	6.60		8.15
8/30/2011	0.50	1.30		4.00	6.90		8.35
9/20/2011	0.50	2.30	4.60		7.00		8.50
10/4/2011	0.50	3.60	7.20		7.20		8.72
10/18/2011	0.50	3.50			6.40	7.40	7.92
11/8/2011	0.50	2.00	4.00		5.20		6.80

Note: *values indicate bottom reading at depth less than depth of the column

Table A27. Water temperature (°C), Site A (2011)

date (mo/day/yr)	water depth (m)										
	0.5	1	2	3	4	5	6	7	8	9	10
6/30/2011	22.03	21.45	21.16	20.90	20.64	20.30	20.10	19.98	19.89	19.66*	
7/13/2011	23.51	23.38	23.32	23.28	23.26	23.23	23.21	23.18	23.15	22.94	22.87*
7/20/2011	28.38	27.57	24.28	23.06	22.80	22.65	22.43	22.33*			
7/27/2011	24.34	24.28	24.21	24.18	23.27	22.81	22.51	22.22	22.01*		
8/3/2011	25.83	25.81	25.35	23.9	22.97	22.49	22.14	21.97	21.8	21.5	
8/17/2011	23.4	23.33	23.25	23.17	23.01	22.14	21.72	21.49	21.2		
8/30/2011	22.87	22.94	22.95	22.81	22.39	21.73	21.21	20.93	20.7		
9/20/2011	16.35	16.36	16.36	16.35	16.35	16.35	16.35	16.35	16.35		
10/4/2011	15.05	15.00	15.00	14.99	15.00	14.99	14.99	14.99	14.98		
10/18/2011	11.5	11.48	11.49	11.49	11.48	11.45	11.45	11.42	11.41*		
11/8/2011	5.38	5.32	5.3	5.29	5.27	5.28	5.28	5.28*			

Note: * values indicate bottom reading at depth less than depth of the column

Table A28. Dissolved oxygen (mg/L), Site A (2011)

date (mo/day/yr)	water depth (m)										
	0.5	1	2	3	4	5	6	7	8	9	10
6/30/2011	9.49	9.69	10.94	10.29	9.78	9.01	8.45	8.16	7.95	0.48*	
7/13/2011	7.27	8.84	8.34	7.84	7.29	6.84	6.59	5.75	4.62	2.60	2.07*
7/13/2011	6.25	6.22	5.43	4.87	4.96	4.75	4.61	4.14	4.14	1.57*	
7/27/2011	7.62	7.23	6.91	6.76	2.27	1.72	1.53	1.34	1.18*		
8/3/2011	7.29	4.62	4.21	1.37	1.08	0.88	1.54	0.64	0.6	0.57	
8/17/2011	5.79	5.08	5.06	4.32	3.01	1.32	0.56	0.39	0.33		
8/30/2011	8.10	8.22	8.27	7.78	2.37	0.77	1.09	0.44	0.46		
9/20/2011	8.43	8.46	8.15	7.98	8.02	8.07	8.02	8.19	7.83		
10/4/2011	5.52	5.47	5.38	5.76	5.58	5.6	5.19	5.28	5.31	5.17	
10/18/2011	7.20	7.17	7.23	7.19	7.22	6.85	6.99	7.04	6.85*		
11/8/2011	12.03	12.57	12.5	12.51	12.54	12.41	8.29	12.37*			

Note: * values indicate bottom reading at depth less than depth of the column

Table A29. Conductivity (mS/cm), Site A (2011)

date (mo/day/yr)	water depth (m)										
	0.5	1	2	3	4	5	6	7	8	9	10
6/30/2011	764	766	766	766	767	766	767	766	767	767*	
7/13/2011	790	792	793	795	796	797	796	795	796	798	801*
7/20/2011	774	780	796	799	800	804	816	821*			
7/27/2011	777	778	780	782	803	812	823	834	848*		
8/3/2011	782	783	792	803	816	832	851	866	877	852	
8/17/2011	793	794	795	801	809	878	905	920	927		
8/30/2011	787	790	800	809	831	905	942	956	976		
9/20/2011	840	842	846	863	867	868	869	870	870		
10/4/2011	897	898	898	897	898	898	898	898	898		
10/18/2011	915	916	917	917	918	918	918	919	918*		
11/8/2011	949	950	951	952	952	952	952	952*			

Note: * values indicate bottom reading at depth less than depth of the column

Table A30. Chlorophyll-*a* (mg/L) and STD (replicates), Site A (2011)

date (mo/day/yr)	water depth					
	at Secchi depth*	at 2 × Secchi depth*	at 1.00m below thermocline*	at 1.50m from the bottom	at 0.50m from the bottom	at Secchi depth*
6/30/2011	2.67±0.76	1.07	6.41		1.60	2.40±1.13
7/13/2011	32.08	34.21	28.87		7.48±1.13	
7/20/2011	79.87	81.01		18.26	10.84	2.28
7/27/2011	74.23	93.98		16.02	5.34	
8/3/2011	48.06±1.13	50.46		21.89	3.20	
8/17/2011	35.24	35.24		18.16	31.51	
8/30/2011	48.59	50.46		20.83	43.25	
9/20/2011	24.03	20.29	22.96		20.29	
10/4/2011	1.60	1.87	2.67		2.67	
10/18/2011	5.87	5.87			5.34	6.94
11/8/2011	28.30	31.51	29.37		32.04	

Note: *depth vary each day and measurements are given in Table A27.

Table A31. Ammonium-nitrogen (mg/L) and STD (replicates), Site A (2011)

date (mo/day/yr)	water depth				
	at Secchi depth*	at 2 × Secchi depth*	at 1.00m below thermocline*	at 1.50m from the bottom	at 0.50m from the bottom
6/30/2011	0.08±				
7/13/2011	0.04				
7/20/2011	0.00		0.00±0.00		0.18
7/27/2011	0.00		0.11	0.23	0.31
8/3/2011	0.01		0.06	0.36	0.78
8/17/2011	0.02		0.01	0.57	0.38
8/30/2011	0.00±0.01		0.00	1.02	1.08
9/20/2011	0.05±0.04	0.00		0.06	
10/4/2011	0.26±0.01			0.24	
10/18/2011	0.27±0.06				
11/8/2011	0.01				0.01±0.01

Note: *depth vary each day and measurements are given in Table A27.

Table A32. Nitrate-nitrogen (mg/L) and STD (replicates), Site A (2011)

Date (mo/day/yr)	water depth				
	at Secchi depth*	at 2 × Secchi depth*	at 1.00m below thermocline*	at 1.50m from the bottom	at 0.50m from the bottom
6/30/2011	0.33±0.01				
7/13/2011	0.12				
7/20/2011	0.15		0.07±0.00		0.07
7/27/2011	0.12		0.10	0.11	0.10
8/3/2011	0.08		0.08	0.09	0.09
8/17/2011	0.07		0.08	0.06	0.10
8/30/2011	0.10±0.02		0.08	0.09	0.09
9/20/2011	0.11±0.00	0.11		0.10	
10/4/2011	0.13±0.00			0.11	
10/18/2011	0.15				
11/8/2011	0.12				0.11±0.01

Note: *depth vary each day and measurements are given in Table A27

Table A33. Nitrite-nitrogen (mg/L) and STD (replicates), Site A (2011)

date (mo/day/yr)	water depth				
	at Secchi depth*	at 2 × Secchi depth*	at 1.00m below thermocline*	at 1.50m from the bottom	at 0.50m from the bottom
6/30/2011	0.01±0.001				
7/13/2011	0.01				
7/20/2011	0.00		0.00±0.00		0.01
7/27/2011	0.00		0.00	0.00	0.00
8/3/2011	0.00		0.00	0.00	0.00
8/17/2011	0.00		0.00	0.00	0.00
8/30/2011	0.00±0.00		0.00	0.00	0.00
9/20/2011	0.00±0.00	0.00		0.00	
10/4/2011	0.01±0.00			0.01	
10/18/2011	0.01±0.00				
11/8/2011	0.00				0.00±0.00

Note: *depth vary each day and measurements are given in Table A27.

Table A35. Total dissolved inorganic nitrogen (mg/L) and STD (replicates), Site A (2011)

date (mo/day/yr)	water depth				
	at Secchi depth*	at 2 × Secchi depth*	at 1.00m below thermocline*	at 1.50m from the bottom	at 0.50m from the bottom
6/30/2011	0.43				
7/13/2011	0.17				
7/20/2011	0.15		0.07		0.26
7/27/2011	0.13		0.20	0.33	0.42
8/3/2011	0.09		0.14	0.45	0.87
8/17/2011	0.09		0.08	0.63	0.48
8/30/2011	0.10		0.08	1.11	1.17
9/20/2011	0.16	0.11		0.17	
10/4/2011	0.39			0.36	
10/18/2011	0.43				
11/8/2011	0.12				0.12

Note: *depth vary each day and measurements are given in Table A27.

Table A36. Total Nitrogen (mg/L) and STD (replicates), Site A (2011)

date (mo/day/yr)	water depth				
	at Secchi depth*	at 2 × Secchi depth*	at 1.00m below thermocline*	at 1.50m from the bottom	at 0.50m from the bottom
6/30/2011	1.27±0.02				
7/13/2011	1.07				
7/20/2011	1.65		1.13±0.03		1.12
7/27/2011	1.93		1.51	1.86	1.96
8/3/2011	2.92		3.29	4.06	2.60
8/17/2011	3.23		3.27	3.93	4.01
8/30/2011	1.56±0.09		1.38	3.46	4.03
9/20/2011	2.13±0.05	1.66		1.55	
10/4/2011	2.42±0.22			2.18	
10/18/2011	2.16±0.06				
11/8/2011	1.93				2.05±0.01

Note: *depth vary each day and measurements are given in Table A27.

Table A37. Total Phosphorus (mg/L) and STD (replicates), Site A (2011)

date (mo/day/yr)	water depth				
	at Secchi depth*	at 2 × Secchi depth*	at 1.00m below thermocline*	at 1.50m from the bottom	at 0.50m from the bottom
6/30/2011	0.15±0.15				
7/13/2011	0.24				
7/20/2011	0.22		0.21±0.02		0.24
7/27/2011	0.22		0.27	0.39	0.47
8/3/2011	0.18		0.24	0.54	0.56
8/17/2011	0.19		0.16	0.40	0.40
8/30/2011	0.30		0.21±0.04	0.67	0.70
9/20/2011	0.25	0.25±0.00		0.25	
10/4/2011	0.24±0.00			0.18	
10/18/2011	0.18±0.01				
11/8/2011	0.12±0.01				0.13

Note: *depth vary each day and measurements are given in Table A27.

Table A38. Soluble Reactive Phosphorus (mg/L) and STD (replicates), Site A (2010)

date (mo/day/yr)	water depth				
	at Secchi depth*	at 2 × Secchi depth*	at 1.00m below thermocline*	at 1.50m from the bottom	at 0.50m from the bottom
6/30/2011	0.06±0.00				
7/13/2011	0.17				
7/20/2011	0.06		0.13±0.00		0.20
7/27/2011	0.09		0.18	0.31	0.37
8/3/2011	0.06		0.13	0.44	0.46
8/17/2011	0.08		0.10	0.31	0.28
8/30/2011	0.06		0.10±0.00	0.46	0.47
9/20/2011	0.11	0.11±0.00		0.11	
10/4/2011	0.15±0.00			0.15	
10/18/2011	0.12±0.00				
11/8/2011	0.03±0.00				0.03

Note: *depth vary each day and measurements are given in Table A27.

A.2.2. Field monitoring and sampling results, Site B (2011)

Table A39. Sampling depths (m), Site B (2011)

date (mo/day/yr)	water depth					
	at surface	Secchi depth	at 2 × Secchi depth	at the thermocline	at 1.50m from the bottom	at 0.50m from the bottom
6/30/2011	0.50	1.90	3.80	NA	5.40	
7/13/2011	0.50	1.80	3.60	NA	5.30	
7/20/2011	0.50	0.80		3.00	3.70	
7/27/2011	0.50	0.80		4.00		
8/3/2011	0.50	1.10		3.00	4.20	
8/17/2011	0.50	1.50		3.00	5.30	
8/30/2011	0.50	1.40		3.00	5.10	
9/20/2011	0.50	2.10	3			
10/4/2011	0.50	3.10				4.80
10/18/2011	0.50	3.00				3.00
11/8/2011	0.50	1.80	3.6			

Table A40. Water temperature (°C), Site B (2011)

date (mo/day/yr)	water depth (m)							
	0.5	1	2	3	4	5	6	7
6/30/2011	22.65	22.54	22.23	21.07	20.71	20.36	20.26	20.10
7/13/2011	23.50	23.40	23.40	23.30	23.30			
7/20/2011	28.71	28.58	24.47	23.30	22.86	22.63		
7/27/2011	24.39	24.17	24.13	23.96	23.33	22.82	22.61	
8/3/2011	25.83	25.85	25.85	23.74	23.07	22.49	22.07*	
8/17/2011	23.45	23.47	23.43	23.19	22.84	22.11	21.73	21.48*
8/30/2011	23.02	23.05	23.00	22.80	22.38	21.79	21.22	20.98*
9/20/2011	16.34	16.35	16.36	16.35				
10/4/2011	15.13	15.12	15.10	15.08	15.08	15.09		
10/18/2011	11.28	11.37	11.38	11.35	11.63*			
11/8/2011	5.28	5.26	5.26	5.26	5.52	5.59*		

Note: *values indicate bottom reading at depth less than depth of the column

Table A41. Dissolved Oxygen (mg/L), Site B (2011)

date (mo/day/yr)	water depth (m)							
	0.5	1	2	3	4	5	6	7
6/30/2011	5.63	5.59	5.11	4.46	4.05	3.65	3.56	3.27
7/13/2011	6.75	6.28	5.97	5.70	5.55			
7/20/2011	9.20	8.52	1.45	1.28	1.08	0.70		
7/27/2011	8.29	6.82	6.01	3.36	1.73	1.39	0	
8/3/2011	6.24	6.29	6.23	6.18	2.78	0.54	0.48*	
8/17/2011	6.24	7.02	6.75	6.86	5.19	2.06	0.64	
8/30/2011	7.69	7.58	7.08	3.53	1.92	1.05	0.48	0.49*
9/20/2011	8.86	8.85	8.40	8.68				
10/4/2011	5.12	5.53	5.56	5.58	5.54	5.63		
10/18/2011	6.54	6.94	6.48	6.96				
11/8/2011	12.06	12.54	12.52	12.73	12.55			

Note: * values indicate bottom reading at depth less than depth of the column

Table A42. Conductivity (mS/cm), Site B (2011)

date (mo/day/yr)	water depth (m)							
	0.5	1	2	3	4	5	6	7
6/30/2011	769	770	771	769	770	769	770	770
7/13/2011	793	792	791	792	793	793	793	747*
7/20/2011	772	776	796	796	798	803		
7/27/2011	782	784	786	794	803	814	814*	
8/3/2011	782	781	782	810	818	852	791	
8/17/2011	795	795	795	797	807	878	909	899*
8/30/2011	801	801	807	812	831	897	946	872*
9/20/2011	871	871	871	871				
10/4/2011	897	897	898	898	898	877		
10/18/2011	920	920	920	920	896*			
11/8/2011	950	951	951	951	948	884*		

Note: * values indicate bottom reading at depth less than depth of the column

Table A43. Chlorophyll-*a* (μg/L) and STD (replicates), Site B (2011)

date (mo/day/yr)	water depth					
	at the Secchi depth*	at the 2 × Secchi depth*	at the 1.00m below thermocline*	at the 1.50m from the bottom	at the 0.50m from the bottom	at the Secchi depth*
6/30/2011	13.35±0.53	11.21	1.07		5.34	
7/13/2011	23.50	22.43	16.02		18.69±3.55	
7/20/2011	63.33	59.05		17.12	7.42	
7/27/2011	92.38	91.85		14.95		
8/3/2011	49.13±1.13	51.53		48.06	30.44	
8/17/2011	39.52	43.52		41.65	33.11	
8/30/2011	35.24	51.53		22.96	31.51	
9/20/2011	27.23	28.3	27.77			
10/4/2011	2.67	2.67				2.403
10/18/2011	5.34	5.61				5.61
11/8/2011	30.97	32.04	30.44			

Note: *depth vary each day and measurements are given in Table A40

Table A44. Ammonia-nitrogen (mg/L) and STD (replicates), Site B (2011)

date (mo/day/yr)	water depth				
	at the Secchi depth*	at the 2 × Secchi depth*	at the 1.00m below thermocline*	at the 1.50m from the bottom	at the 0.50m from the bottom
6/30/2011	0.22				
7/13/2011	0.03±0.00				
7/20/2011	0.00		0.00	0.02	
7/27/2011	0.00		0.10±0.00		
8/3/2011	0.00		0.00	0.16	0.51
8/17/2011	0.00		0.00	0.37	0.87
8/30/2011	0.00		0.01	0.34	0.86
9/20/2011	0.05			0.03	
10/4/2011	0.24				0.22
10/18/2011	0.30				
11/8/2011	0.01	0.01			

Note: *depth vary each day and measurements are given in Table A40

Table A45. Nitrate-nitrogen (mg/L) and STD (replicates), Site B (2011)

date (mo/day/yr)	water depth				
	at the Secchi depth*	at the 2 × Secchi depth*	at the 1.00m below thermocline*	at the 1.50m from the bottom	at the 0.50m from the bottom
6/30/2011	0.32				
7/13/2011	0.11±0.005				
7/20/2011	0.06		0.06	0.05	
7/27/2011	0.09		0.09±0.00		
8/3/2011	0.07		0.07	0.08	0.09
8/17/2011	0.07		0.06	0.08	0.07
8/30/2011	0.05		0.06	0.06	0.07
9/20/2011	0.09			0.09	
10/4/2011	0.14				0.12
10/18/2011	0.16				
11/8/2011					

Note: *depth vary each day and measurements are given in Table A40.

Table A46. Nitrite-nitrogen (mg/L) and STD (replicates), Site B (2011)

date (mo/day/yr)	water depth				
	at the Secchi depth*	at the 2 × Secchi depth*	at the 1.00m below thermocline*	at the 1.50m from the bottom	at the 0.50m from the bottom
6/30/2011	0.01				
7/13/2011	0.01±0.00				
7/20/2011	0.01		0.00	0.00	
7/27/2011	0.00		0.00±0.00		
8/3/2011	0.00		0.00	0.00	
8/17/2011	0.00		0.00	0.00	0.00
8/30/2011	0.00		0.00	0.00	0.00
9/20/2011	0.00			0.00	
10/4/2011	0.00				0.00
10/18/2011	0.01				
11/8/2011	0.00	0.00			

Note: *depth vary each day and measurements are given in Table A40.

Table A47. Total Dissolved Inorganic Nitrogen (mg/L), Site B (2011)

date (mo/day/yr)	water depth				
	at the Secchi depth*	at the 2 × Secchi depth*	at the 1.00m below thermocline*	at the 1.50m from the bottom	at the 0.50m from the bottom
6/30/2011	1.86				
7/13/2011	0.81				
7/20/2011	1.12		1.44	1.00	
7/27/2011	1.51		1.65		
8/3/2011	2.14		2.19	2.20	2.41
8/17/2011	2.68		2.67	3.29	4.01
8/30/2011	1.41		1.91	1.79	2.61
9/20/2011	1.49			1.47	
10/4/2011	1.53				1.50
10/18/2011	1.99				
11/8/2011	1.41	1.48			

Note: *depth vary each day and measurements are given in Table A40.

Table A48. Total Nitrogen (mg/L) and STD (replicates), Site B (2011)

date (mo/day/yr)	water depth (m)				
	at the Secchi depth*	at the 2 × Secchi depth*	at the 1.00m below thermocline*	at the 1.50m from the bottom	at the 0.50m from the bottom
6/30/2011	1.33				
7/13/2011	0.97±0.06				
7/20/2011	1.46		1.12	1.07	
7/27/2011	2.38		1.89±0.05		
8/3/2011	2.55		5.22	2.56	2.55
8/17/2011	3.18		3.21	3.54	4.04
8/30/2011	1.70		1.60	2.56	2.83
9/20/2011	1.83			1.51	
10/4/2011	1.78				1.68
10/18/2011	2.03				
11/8/2011	1.65	1.53			

Note: *depth vary each day and measurements are given in Table A40.

Table A49. Total Phosphorus (mg/L) and STD (replicates), Site B (2011)

date (mo/day/yr)	water depth				
	at the Secchi depth*	at the 2 × Secchi depth*	at the 1.00m below thermocline*	at the 1.50m from the bottom	at the 0.50m from the bottom
6/30/2011	0.16				
7/13/2011	0.24±0.00				
7/20/2011	0.20		0.21	0.21	
7/27/2011	0.25±0.00		0.22		
8/3/2011	0.22		0.20	0.30	0.42
8/17/2011	0.17		0.16	0.56	0.52
8/30/2011	0.34		0.19	0.50	0.44
9/20/2011	0.21			0.21	
10/4/2011	0.23				0.29
10/18/2011	0.17				
11/8/2011	0.13	0.14			

Note: *depth vary each day and measurements are given in Table A40

Table A50. Soluble Reactive Phosphorus (mg/L) and STD (replicates), Site B (2011)

date (mo/day/yr)	water depth (m)				
	at the Secchi depth*	at the 2 × Secchi depth*	at the 1.00m below thermocline*	at the 1.50m from the bottom	at the 0.50m from the bottom
6/30/2011	0.06				
7/13/2011	0.17±0.01				
7/20/2011	0.06		0.12	0.13	
7/27/2011	0.09±0.00		0.17		
8/3/2011	0.06		0.06	0.20	0.31
8/17/2011	0.09		0.09	0.22	0.39
8/30/2011	0.06		0.07	0.26	0.41
9/20/2011	0.11			0.11	
10/4/2011	0.14				0.14
10/18/2011	0.12				
11/8/2011	0.03	0.03			

Note: *depth vary each day and measurements are given in Table A40

A2.3. Field monitoring and sampling results, Site C (2011)

Table A51. Sampling depths (m), Site C (2011)

date mo/day/yr	water depth (m)		
	at the Surface	at the Secchi depth	at the 0.50m from the bottom
6/30/2011	0.50	1.90	3.90
7/13/2011	0.50	1.90	2.60
7/20/2011	0.50	0.90	2.50
7/27/2011	0.50	0.90	2.80
8/3/2011	0.50	1.00	2.90
8/17/2011	0.50	1.50	2.90
8/30/2011	0.50	1.20	2.80
9/20/2011	0.50	2.00	3.70
10/4/2011	0.50	2.00	3.70
10/18/2011	0.50	2.86	
11/8/2011	0.50	1.80	3.60

Table A52. Water temperature (°C), Site C (2011)

date mo/day/yr	water depth (m)				
	0.5	1	2	3	4
6/30/2011	22.91	22.40	21.91	21.29	20.73
7/13/2011	23.74	23.50	23.40	23.10	23.00
7/20/2011	28.08	26.99	24.34	23.06	22.79
7/27/2011	24.86	24.66	24.16	23.89	23.30
8/3/2011	26.18	25.93	25.66	24.87	23.04
8/17/2011	23.68	23.31	23.24	23.17	22.99
8/30/2011	22.99	23.04	23.03	22.98	22.47
9/20/2011	16.34	16.34	16.33	16.33	16.32
10/4/2011	15.29	15.17	15.13	15.11	15.10
10/18/2011	11.27	11.35	11.28	11.42	
11/8/2011	5.14	5.12	4.99	4.94	4.83*

Note: *values indicate bottom reading at depth less than depth of the column

Table A53. Dissolved Oxygen (mg/L), Site C (2011)

date mo/day/yr	water depth (m)				
	0.5	1	2	3	4
6/30/2011	11.58	11.32	10.05	8.32	3.28
7/13/2011	8.46	8.49	8.51	8.56	8.58
7/20/2011	7.81	7.97	8.36	8.57	8.61
7/27/2011	8.28	8.31	8.39	8.43	8.53
8/3/2011	6.43	6.39	5.03	2.35	0.92
8/17/2011	6.72	6.94	6.63	6.49	6.47
8/30/2011	7.55	7.49	7.91	7.57	3.84
9/20/2011	8.37	8.31	8.27	8.28	8.12
10/4/2011	5.40	5.67	5.59	5.61	5.54
10/18/2011	7.40	7.49	7.47	5.61	
11/8/2011	11.51	11.41	11.69	11.71	11.95*

Note: * values indicate bottom reading at depth less than depth of the column

Table A54. Conductivity (mS/cm), Site C (2011)

date mo/day/yr	water depth (m)				
	0.5	1	2	3	4
6/30/2011	767	768	768	770	777
7/13/2011	784	785	785	786	784
7/20/2011	781	794	799	800	800
7/27/2011	779	781	791	796	797
8/3/2011	779	780	784	780	812
8/17/2011	794	795	794	794	805
8/30/2011	800	800	799	803	821
9/20/2011	870	870	870	870	870
10/4/2011	896	896	897	897	898
10/18/2011	928	928	928	924	
11/8/2011	952	952	953	953	954

Note: * values indicate bottom reading at depth less than depth of the column

Table A55. Chlorophyll-*a* (µg/L) and STD (replicates), Site C (2011)

date mo/day/yr	water depth		
	at the surface 0.5m	at the Secchi depth	at the 0.50m from the bottom
6/30/2011	18.6900	13.0830	14.4180±1.89
7/13/2011	38.9820	25.0980	17.0880
7/20/2011	34.8013	38.2244	6.8462
7/27/2011	56.0700	69.4200	22.4280
8/3/2011	46.9920±1.51	54.4680	20.8260
8/17/2011	41.6520	32.3070	30.4380
8/30/2011	45.9240	48.5940	48.5940
9/20/2011	30.4380	29.3700	18.6900
10/4/2011	2.1360	2.6700	1.0680
10/18/2011	6.9420	7.2090	
11/8/2011	33.1080	34.1760	29.9040

Note: *depth vary each day and measurements are given in Table A52

Table A56. Ammonia-nitrogen (mg/L) and STD (replicates), Site C (2011)

date mo/day/yr	at the Secchi depth
6/30/2011	0.02
7/13/2011	0.01
7/20/2011	0.00
7/27/2011	0.001
8/3/2011	0.005±0.01
8/17/2011	0.01
8/30/2011	0.00
9/20/2011	0.03
10/4/2011	0.21
10/18/2011	0.29
11/8/2011	0.01

Note: *depth vary each day and measurements are given in Table A52

Table A57. Nitrite-nitrogen (mg/L) and STD (replicates), Site C (2011)

date mo/day/yr	at the Secchi depth
6/30/2011	0.35
7/13/2011	0.11
7/20/2011	0.06
7/27/2011	0.09
8/3/2011	0.07±0.00
8/17/2011	0.06
8/30/2011	0.05
9/20/2011	0.09
10/4/2011	0.11
10/18/2011	0.15
11/8/2011	0.11

Note: *depth vary each day and measurements are given in Table A52

Table A58. Nitrate-nitrogen (mg/L) and STD (replicates), Site C (2011)

date mo/day/yr	at the Secchi depth
6/30/2011	0.01
7/13/2011	0.01
7/20/2011	0.00
7/27/2011	0.00
8/3/2011	0.00±0.00
8/17/2011	0.00
8/30/2011	0.00
9/20/2011	0.00
10/4/2011	0.00
10/18/2011	0.02
11/8/2011	0.00

Note: *depth vary each day and measurements are given in Table A52

Table A59. Total Dissolved Inorganic Nitrogen (mg/L), Site C (2011)

date mo/day/yr	at the Secchi depth
6/30/2011	0.38
7/13/2011	0.12
7/20/2011	0.06
7/27/2011	0.09
8/3/2011	0.08
8/17/2011	0.07
8/30/2011	0.05
9/20/2011	0.13
10/4/2011	0.33
10/18/2011	0.46
11/8/2011	0.12

Note: *depth vary each day and measurements are given in Table A52

Table A60. Total nitrogen (mg/L) and STD (replicates), Site C (2011)

date mo/day/yr	at the Secchi depth*
6/30/2011	1.26
7/13/2011	0.93
7/20/2011	1.34
7/27/2011	2.22
8/3/2011	2.77±2.77
8/17/2011	2.85
8/30/2011	1.70
9/20/2011	1.62
10/4/2011	2.07
10/18/2011	2.03
11/8/2011	1.68

Note: *depth vary each day and measurements are given in Table A52

Table A61. Total Phosphorus (mg/L) and STD (replicates), Site C (2011)

Date mo/day/yr	at the Secchi depth*
6/30/2011	0.14
7/13/2011	0.21
7/20/2011	0.21
7/27/2011	0.22
8/3/2011	0.18±0.00
8/17/2011	0.34
8/30/2011	0.35
9/20/2011	0.24
10/4/2011	0.23
10/18/2011	0.18
11/8/2011	0.13

Note: *depth vary each day and measurements are given in Table A52

Table A62. Soluble Reactive Phosphorus (mg/L) and STD (replicates), Site C (2011)

date mo/day/yr	at the Secchi depth
6/30/2011	0.12
7/13/2011	0.18
7/20/2011	0.12
7/27/2011	0.22
8/3/2011	0.15±0.01
8/17/2011	0.13
8/30/2011	0.11
9/20/2011	0.15
10/4/2011	0.20
10/18/2011	0.15

Note: *depth vary each day and measurements are given in Table A52

A2.4. Field monitoring and sampling results, Site D (2011)

Table A63. Sampling depths (m), Site D (2011)

date mo/day/yr	water depth (m)		
	at surface	at Secchi depth	at 0.50m from the bottom
6/30/2011	0.50	2.00	3.50
7/13/2011	0.50	2.00	2.50
7/20/2011	0.50	0.80	3.60
7/27/2011	0.50	0..90	2.80
8/3/2011	0.50	1.10	3.30
8/17/2011	0.50	1.20	3.10
8/30/2011	0.50	1.30	2.40
9/20/2011	0.50	2.00	4.00
10/4/2011	0.50	4.00	3.80
10/18/2011	0.50	3.50	
11/8/2011	0.50	1.90	3.80

Table A64. Water temperature (°C), Site D (2011)

date mo/day/yr	water depth (m)					
	0.5	1	2	3	4	5
6/30/2011	23.36	22.81	22.37	21.69	20.97	20.48
7/13/2011	23.30	23.50	23.40	23.30	23.10	
7/20/2011	28.91	28.72	25.08	23.23	22.97	22.95
7/27/2011	24.80	24.60	24.18	24.01	23.4	
8/3/2011	26.20	26.17	25.66	25.40	23.04	22.85*
8/17/2011	24.14	23.72	23.52	23.28	23.06	
8/30/2011	22.98	22.98	22.97	22.79	22.60*	
9/20/2011	16.32	16.35	16.34	16.34	16.33	
10/4/2011	15.22	15.19	15.14	15.09	15.08	
10/18/2011	11.42	11.42	11.41	11.38	11.30*	
11/8/2011	4.99	4.98	4.85	4.83	4.76	

Note: *values indicate bottom reading at depth less than depth of the column

Table A65. Dissolved Oxygen (mg/L), Site D (2011)

date mo/day/yr	water depth (m)					
	0.50	1	2	3	4	5
6/30/2011	10.08	9.89	8.88	6.10	6.52	0.82
7/13/2011	6.86	6.77	6.50	6.01	5.71	
7/20/2011	8.97	8.76	1.22	1.01	0.83	0.69
7/27/2011	7.87	8.17	6.9	5.32	1.37	
8/3/2011	7.4	7.57	6.84	4.67	1.45	0.9*
8/17/2011	7.85	8.58	8.09	8.17	6.57	
8/30/2011	7.41	7.39	7.43	6.1	3.29*	
9/20/2011	9.16	9.02	8.92	9.07	8.86	
10/4/2011	5.82	6.03	5.92	5.85	5.61	
10/18/2011	7.4	7.4	7.52	7.29	7.57	
11/8/2011	12.69	13.28	13.48	13.34	12.97*	

Note: * values indicate bottom reading at depth less than depth of the column

Table A66. Conductivity (mS/cm), Site D (2011)

date mo/day/yr	water depth (m)					
	0.5	1	2	3	4	5
6/30/2011	769	769	770	773	773	991
7/13/2011	769	783	786	786	754	
7/20/2011	775	775	799	804	808	1107
7/27/2011	784	783	785	788	809	
8/3/2011	781	781	785	789	856	1006*
8/17/2011	792	793	793	796	795	
8/30/2011	801	801	803	812	817*	
9/20/2011	872	872	872	872	875	
10/4/2011	900	901	901	900	909	
10/18/2011	920	920	920	920	920	
11/8/2011	950	951	953	953	959	

Note: * values indicate bottom reading at depth less than depth of the column

Table A67. Chlorophyll-*a* (mg/L) and STD (replicates), Site D (2011)

date mo/day/yr	water depth				
	at Surface	at Secchi depth*	at 2 × Secchi depth*	at 1.5m from the bottom	at 0.5m from the bottom
6/30/2011	14.42	13.88		10.95±0.39	
7/13/2011				21.63±1.13	
7/20/2011	57.05	60.76		12.55	
7/27/2011	56.07	58.47		52.87	
8/3/2011	45.39±15.38	48.59		13.88	
8/17/2011	115.34	62.48		39.52	
8/30/2011	55.54	63.55		57.67	
9/20/2011	36.31	30.17			16.02
10/4/2011	2.14	2.40			2.14
10/18/2011	4.27	5.07			
11/8/2011	23.50	24.03	21.89		

Note: *depth vary each day and measurements are given in Table A64

Table A68. Ammonia-nitrogen (mg/L) and STD (replicates), Site D (2011)

date mo/day/yr	water depth (m)
	at the Secchi depth*
6/30/2011	0.02
7/13/2011	0.02
7/20/2011	0.00
7/27/2011	0.02
8/3/2011	0.00
8/17/2011	0.00±0.00
8/30/2011	0.01
9/20/2011	0.00
10/4/2011	0.21
10/18/2011	0.31
11/8/2011	0.01

Note: *depth vary each day and measurements are given in Table A64

Table A69. Nitrate-nitrogen (mg/L) and STD (replicates), Site D (2011)

date mo/day/yr	water depth (m) at the Secchi depth*
6/30/2011	0.26
7/13/2011	0.10
7/20/2011	0.05
7/27/2011	0.09
8/3/2011	0.07
8/17/2011	0.07±0.00
8/30/2011	0.05
9/20/2011	0.08
10/4/2011	0.13
10/18/2011	0.15
11/8/2011	0.10

Note: *depth vary each day and measurements are given in Table A64

Table A70. Total dissolved inorganic nitrogen (mg/L), Site D (2010)

date mo/day/yr	water depth (m) at the Secchi depth*
6/30/2011	0.28
7/13/2011	0.12
7/20/2011	0.05
7/27/2011	0.11
8/3/2011	0.07
8/17/2011	0.07
8/30/2011	0.07
9/20/2011	0.08
10/4/2011	0.34
10/18/2011	0.46
11/8/2011	0.11

Table A71. Nitrite-nitrogen (mg/L), Site D (2011)

date mo/day/yr	water depth (m) at the Secchi depth*
6/30/2011	0.01
7/13/2011	0.01
7/20/2011	0.00
7/27/2011	0.00
8/3/2011	0.00
8/17/2011	0.00
8/30/2011	0.00
9/20/2011	0.00
10/4/2011	0.00
10/18/2011	0.01
11/8/2011	0.00

Note: *depth vary each day and measurements are given in Table A64

Table A72. Total Nitrogen (mg/L) and STD (replicates), Site D (2011)

date mo/day/yr	water depth (m) at the Secchi depth*
6/30/2011	1.24
7/13/2011	0.97
7/20/2011	1.43
7/27/2011	3.02
8/3/2011	3.18
8/17/2011	3.29±0.06
8/30/2011	1.78
9/20/2011	1.92
10/4/2011	1.82
10/18/2011	1.96
11/8/2011	1.58

Note: *depth vary each day and measurements are given in Table A64

Table A73. Soluble Reactive Phosphorus (mg/L) and STD (replicates), Site D (2011)

date mo/day/yr	water depth (m) at the Secchi depth*
6/30/2011	0.05
7/13/2011	0.16
7/20/2011	0.06
7/27/2011	0.09
8/3/2011	0.06
8/17/2011	0.08±0.00
8/30/2011	0.07
9/20/2011	0.11
10/4/2011	0.14
10/18/2011	0.12
11/8/2011	0.03

Note: *depth vary each day and measurements are given in Table A64

Table A74. Total Phosphorus (mg/L) and STD (replicates), Site D (2011)

date mo/day/yr	water depth (m) at Secchi depth*
6/30/2011	0.13
7/13/2011	0.23
7/20/2011	0.20
7/27/2011	0.21
8/3/2011	0.20
8/17/2011	0.25±0.06
8/30/2011	0.40
9/20/2011	0.26
10/4/2011	0.22
10/18/2011	0.19
11/8/2011	0.12

Note: *depth vary each day and measurements are given in Table A64

APPENDIX B. PROCEDURE FOR DEPTH-WEIGHTED AVERAGE CALCULATIONS

The designed sampling depths for nutrient and phytoplankton were not evenly distributed over the water column and vary each sampling the event. To average nutrient and phytoplankton concentrations taken across the designed depths the weighted average method was used considering depth taken as a "weight". The procedure of depth-weighted averaging of concentrations will be provided in this section.

B1. Procedures

B1.1. Determine boundaries of water layers representing sampling water depths

The water column was divided by layers as shown in Figure B1.

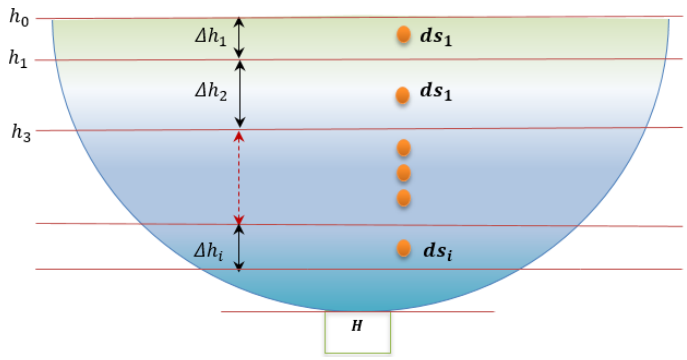

Figure B1. Illustrated water column divided in water layers.

where $ds_{1,2,\ldots,i}$-sampling depths, $h_{1,2,\ldots,i} - water\ depth\ defined\ as: h_i = \frac{d_{i+1} + d_i}{2}$, $\Delta h_{1,2,\ldots,i}$ – thickness of each sampling layer $\Delta h_i = h_i + h_{i-1}$, H – total water depth

B1.2. Calculations of depth-weighted average value and depth-weighted average Standard Deviation

The depth-weighted average is calculated by sum of multiplying the assumed depths by measured values for each variable, and the sum is divided by maximum depth at each event (Equiqtion B1).To calculate Total TP or TN load for entire lake the calculation will include site-specific depth-weighted averaged concentrations. That means for each site A, B, C, and D the concentrations average will be calculated separately.

$$C_{av} = \frac{(\Delta h_1 \times c_1)+(\Delta h_2 \times c_2)+\cdots\ldots(\Delta h_i \times c_i)}{H} \qquad \text{(Equation B1)}$$

where: c_i – concentrations measured at designed depths (mg/L),
Δh_i– assumed water column layers (m)
H– water column depth $H = \Delta h_1 + \Delta h_2 + \Delta h_i$

Calculation of weighted standard deviation of depth-averaged concentrations

$$sd_w = \sqrt{\frac{\sum_{i=1}^{N} w_i (x_i - \bar{x}_w)^2}{\frac{(N' - 1)\sum_{i=1}^{N} w_i}{N'}}} \qquad \text{(Equation B2)}$$

where: w_i – weight for the i-th observation,
N' – number of non-zero weights
x_w - weighted mean of the observations

APPENDIX C. PHYTOPLANKTON COUNTING PROCEDURE AND SPECIES IDENTIFICATION

Lake water samples contain numerous and diverse numbers of phytoplankton cells and species, which vary in space and time. Essential parts of sample phytoplankton analyses include species identification and counting. Measuring the phytoplankton abundance distribution (vertical and horizontal) is required to evaluate the effect of lake physical and chemical characteristics on phytoplankton growth. For determining phytoplankton abundance, direct counting is undertaken following the Utermöl (1958) technique. The principle of the technique includes homogenization of the sample after which a sub-sample is placed in a sedimentation chamber. After a required period of time phytoplankton cells that settled to the bottom of the chamber are identified and counted using inverted microscopy. The details of phytoplankton identification and enumeration (counting) in water samples are presented in this section.

C1. Procedures

C1.2. Materials

Counting chamber. The Sedgwick-Rafter chamber (SRC) was used for phytoplankton counting and species identification. This SRC consists of a 2mm thick clear base slide (76 x 40 mm), onto which a rectangular chamber (50mm long x 20mm wide and 1mm deep) was mounted. The base of the chamber is marked with a grid of 1 x 1mm squares to assist with counting (Figure C1). The volume of the chamber was 1 ml and each of the quadrant equates was1microlitre of liquid.

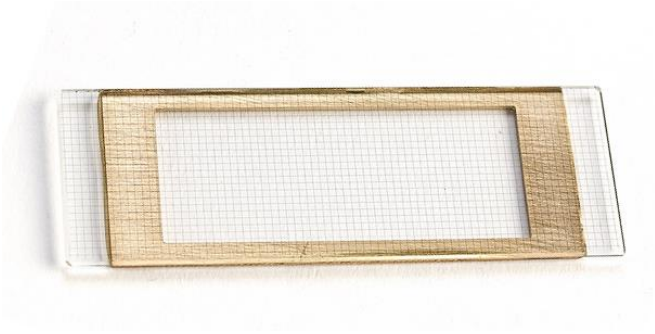

Figure C1. Sedgwick-Rafter chamber for counting of phytoplankton units.

Microscope. Two inverted microscopes were used: *Leica and Carl Zeiss Axio Observer Z1* (Figure. C2) at long working distance condenser at magnification lenses 10x, 20x and 40x (*Leica and Carl Zeiss*, and at 60x (*Carl Zeiss*) magnification. Both microscopes were equipped with digital cameras.

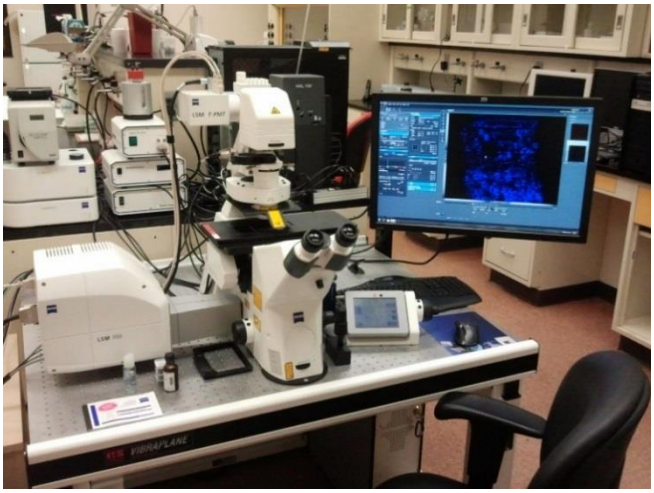

Figure C2. Carl Zeiss Axio Observer Z1, located in Advance Image Analysis (AIM) Lab, NDSU.

C2. Methods for Sample Preparation and Phytoplankton Counting and Identification

C2.1. Sample concentration

Fife hindered 500 ml samples were taken and preserved in the field with Lugol's solution then concentrated before being analyzed. The samples were set aside for sedimentation for at least for two weeks. At the end of the settling period, the supernatant from the original 500 ml sample was siphoned off without disturbing settled materials to

obtain a final volume (decant) close to 50 ml. The decant was rotated to capture the phytoplankton cells adhered to the wall and was transferred into pre-labeled 50 ml storage bottles. The supernatant and final volumes are recorded for calculating of dilution factors.

C2.2. Pre-counting sample preparation

Before filling the SRC, the sample was thoroughly mixed, treated with a few drops of Lugol's solution, mixed again, and allowed to stand for 30 to 60 minutes.

C2.3. Filling the Sedgwick-Rafter chamber

The cover slip was placed diagonally across the SRC. Placing the cover slip in this way prevent formation of air bubbles in the cell corners. After homogenization of the sample by repeatedly inverting the sample bottle (10-15 times), a 1ml sample was taken and transferred to the chamber, following the steps in Figure C3. Overfilling the chamber will make the depth greater than 1mm and invalidate the calculations. The cover slip was rotated slowly and to cover the inner portion of the cell during filling (Figure C3, f). The phytoplankton sample was placed into the SRC was allowed to stand on a flat surface for 15-20 minutes to enable the phytoplankton to settle to the bottom.

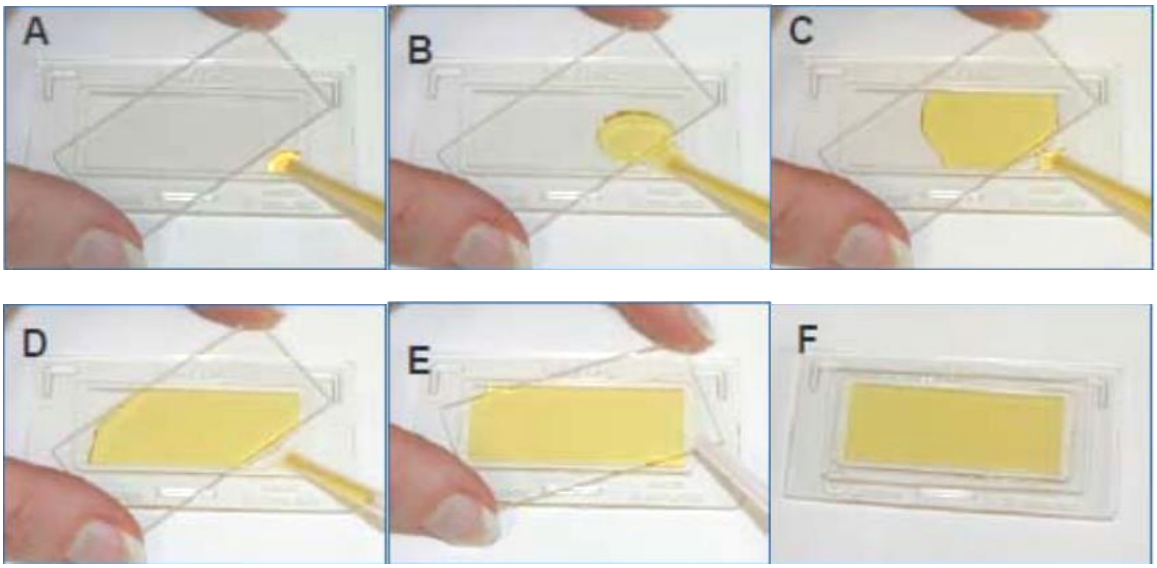

Figure C3. Steps for filling SRCamber with a sample for phytoplankton counting.

The phytoplankton sample was placed into the SRC was allowed to stand on a flat surface for 15-20 minutes to enable the phytoplankton to settle to the bottom.The prepared SRC was transferred to the stage of inverted light microscope and securely positioned.

C2.4. Number of counting fields in the Sedgwick-Rafter chamber

The phytoplankton units were counted on the bottom of the chamber in random fields each consisting of one grid (Figure C4). The number of fields counted depends on the density of the phytoplankton and the statistical accuracy desired. To obtain at least 400 number of phytoplankton units from each sample, 95% confidence limit, 20 or 25 fields was used in this study.

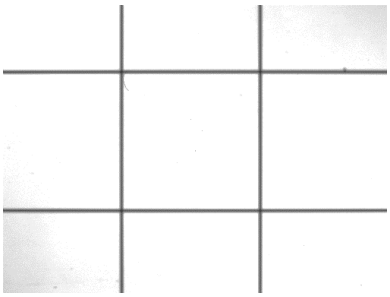

Figure C4. SRC grid view at 5x magnification.

C2.5. Precision

The phytoplankton units often laid over the grid lines. In this case, the CEN (2004) rule was followed – the units crossing the bottom or right hand side of the grid were counted, while those crossing both the top and the left hand side of the grid were not counted (Figure C5).

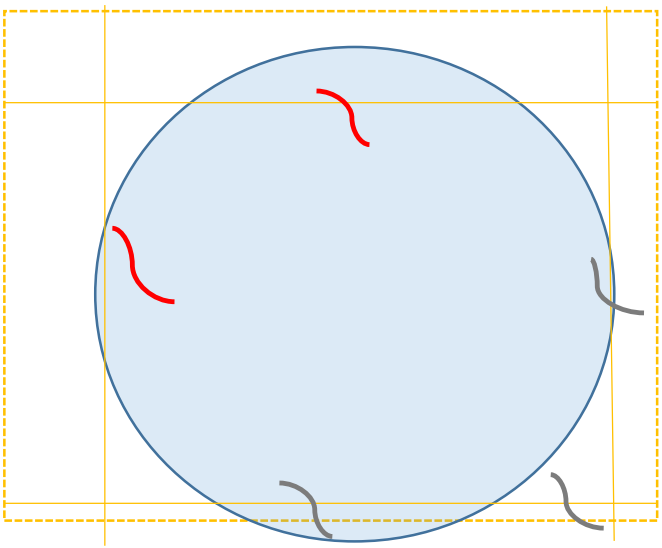

Figure C5. Counting rule for phytoplankton units lying on the edge of the grid in SRC. The red units –not counted, the green units counted.

C2.6. Species identification

Phytoplankton were identified to genus level. The guides for identification used were the Freshwater Algal Flora of the British Isles (John et al., 2012), Algae Identification: Field guide (Huynh & Serediak, 2006), Freshwater Algae: Identification and use as Bioindicators (Bellinger et al., 2010), Freshwater Algae of North America (Elsevier Science, 2003). The images of most of the key species are include in APPENDIX E.

The number of phytoplankton units per 1mL (SRC volume) were calculated as follows:

$$No./ml = \frac{C \times 1000}{A \times D \times F} \qquad \text{(Equation C1)}$$

where: C – number of phytoplankton units (cells, colonies and filaments) counted,
A – area of field (grid image area) (mm),
D –-cell depth (mm)
F – number of fields

C2.7. Calculations

To determine phytoplankton unit concentration in the sample, the number of cells per milliliter (Equation C2) was multiplied by a concentration factor to adjust for sample dilution as follows.

$$No.\frac{phytoplankton\ unit}{L} = CF \times No./ml \qquad \text{(Equation C2)}$$

where: No.– phytoplankton unit (cells or filaments or colonies) counted,
CF – concentration factor calculated as:

$$CF\ (l) = \frac{final\ volume\ (ml)}{final\ volume + supernatant\ (ml)} \times 1000 \qquad \text{(Equation C3)}$$

The counts for individual taxa were converted to phytoplankton biovolume ($\mu m^3/l$) by using the cell/unit biovolume of the count units following Phytoplankton Biovolume Determination procedure in the next APPENDIX D.

References:

CEN (2004). Water quality – Guidance standard for the routine analysis of phytoplankton abundance and composition using inverted microscopy (Utermöhl technique)

Lund,J.W.G., Kipling,C. and Le Cren,E.D. (1958) The inverted microscope method of estimating algal numbers and the statistical basis of estimations by counting.*Hydrobiol.*,11,143–170.

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APPENDIX D: PHYTOPLANKTON BIOVOLUME DETERMINATION

The biovolume of each phytoplankton species was determined by multiplying the unit volume of each individual cell, filament or colony by the abundance of these structures in the sample. The biovolume of each unit (cells, filaments or colony) was determined using image analysis and commonly accepted shapes of species studied. The details of unit biovolume determination for each sample are presented in this section.

D1. Procedure

D1.1. Image analysis

Image acquisition was carried out with inverted microscopes equipped with digital cameras*: Leica* at 10x, 20x and 40x magnification and *Carl Zeiss Axio Observer Z1* at 10x, 20x, 40x and 60x magnification. For image analysis of the phytoplankton, the Image-Pro Plus 4.5 software was used to measure phytoplankton unit (cell, filament or colony) dimensions, including length (l), diameter (d), width (w) in microns (for length) or microns squared (for area).

The *Image-Pro Plus 4.5* calibration tool was used to calibrate each lens-camera-resolution combination for both the *Leica* and *Carl Zeiss Axio Observer Z1* (Zeiss) inverted microscopes. The microscope calibration was confirmed using the same stage micrometer slide for all lenses, and the number of pixels per micron was determined for each magnification used. The Spatial Calibration tool was used to record calibration parameters for measuring unit biovolume dimensions. In addition, *Zeiss AxioVision* software stores information of all *Zeiss* microscope components used for imaging and automatically, which provides proper calibration units for each magnification that can be used in the *ImagePro-Plus 4.5* Calibration Tool.

D2. Unit Biovolume Determination. Method I: Area and Depth

This method was used for measuring species that form flat colonies, such as *Pediastrum* sp., or have relatively constant cell heights, such as *Cymbella* sp. and *Cocconeis* sp. Unit biovolume (*Vu*) of this type of phytoplankton species were determined by multiplying measured colony/cell area (A) to the depth (h) of the colony/cell (Equiation D1).

$$V_u = A \times h \qquad \text{(Equation D1)}$$

where: V_u – unit biovolume (μm^3)
A – area (μm^2)
h – depth (μm)

D2.1. Area determination

A flat colony usually settles on its flat side (aligned horizontally along the slide) like the one cell thick colony of *Pediastrum sp.* (Figure D1., a). Similarly, most of the cells of Class Bacillariophyceae, such as *Epithemia* sp. and *Cocconeis* sp. settle on their valve sides. To extract the specimen (area) of interest and to distinguish it from the other objects, the threshold in *Image-Pro Plus 4.5* option was used (Figure D1, a). Count/Size dialog box and the *Intensity Range* Selection options were applied to measure the area of a colony or a cell.

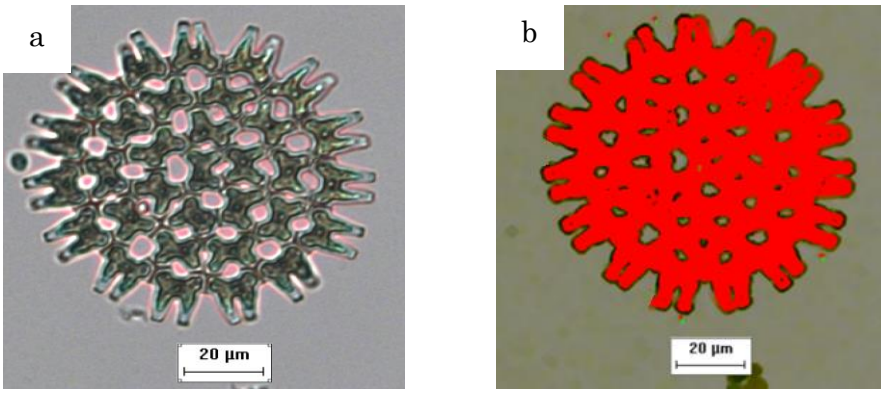


Figure D1. *Pediastrum* sp. (a) colony and (b) applied Intensity Range Selection options for measure the area of Pediastrum sp. colony.

D2.2. Colony/cell depth determination

The depth of the colony or cell described in D2.1.1 most of time is difficult to obtain. The following procedures were developed and used to determine or estimate depth values. Sometimes, a colony or a cell folded at the edge of or grid of the chamber (aligned vertically along the slide) as shown in Figure D2 a and Figure D3. Then the depth of the cell or colony could be measured directly from the image. Because, the depth may vary from colony to colony, or from cell to cell, an effort was made to identify a representative length from the flat image of the colony or cell (Figure D2., b and Figure D3).

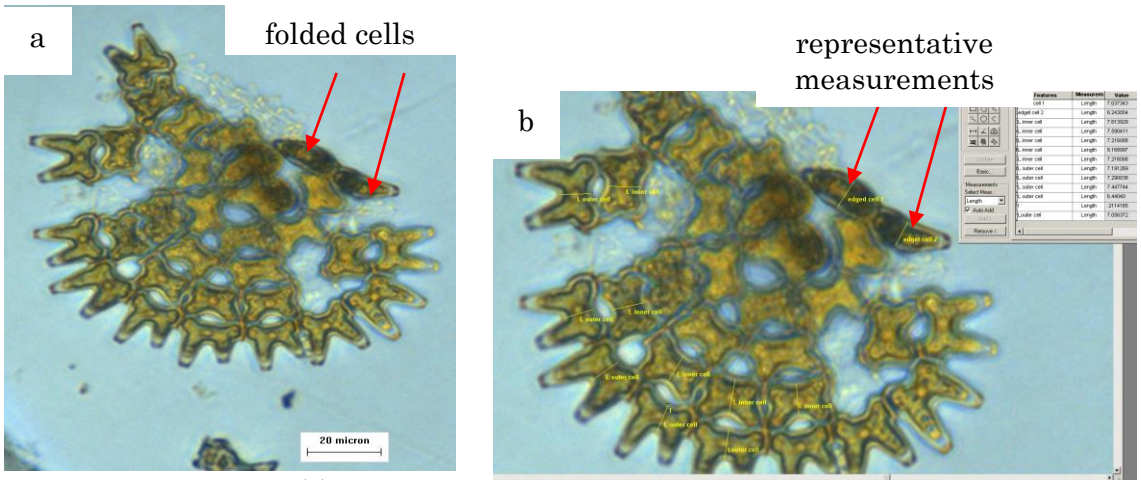


Figure D2. ***Pediastrum*** **sp. (a) colony with folded cells and (b) representative measurements from folded cells of** ***Pediastrum*** **sp.**

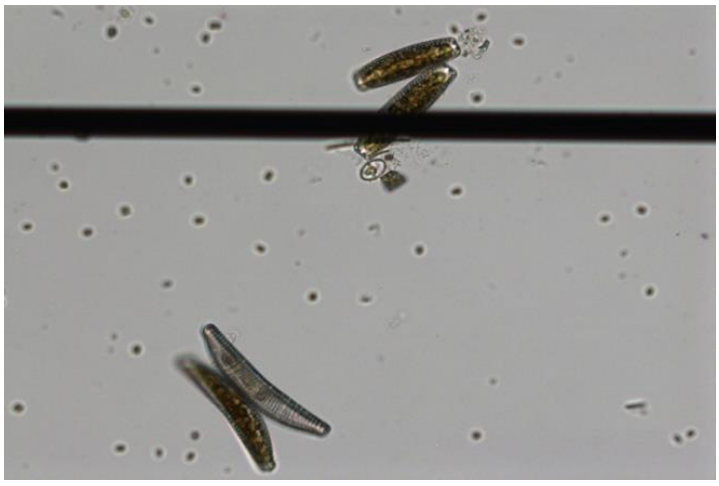


Figure D3. ***Cymbella*** **sp. cells valve view and folded cells.**

After a representative length of the depth is identified, multiple measurements of this representative length were taken and averaged. In the case of no representative dimension could be identified, the average depth measured from folded colonies or standing on their sides cells were used as a constant value for all the samples. If no folded colony of a species was found, depth value from the literature was used in colony biovolume estimations.

D3. Method II: Cross Section Area and Length

This method was used for determining unit volume of filamentous species with cylindrical shapes, such as *Aphanizomenon sp.* and *Anabaena sp.* using Equation. D2:

$$V_u = A \times L \qquad \text{(Equation D2)}$$

where: V_u – unit biovolume (μm^3)
A – area (μm^2)
L – length (μm)

D3.1. Cross sectional area determination

The diameter was measured using *Image-Pro Plus 4.5.* Then the cross sectional area was calculated by Equation. D3:

$$Ac = \frac{\pi}{4} \times d^2 \qquad \text{(Equation D3)}$$

where: Ac –cross sectional area (μm^2)
d –diameter (μm)

D3.2. Length (L) determination

The length was measured using *Image-Pro Plus 4.5.* If the *length* of the filament could not be easily taken from the image, for example, the filaments of *Anabaena* sp. clumped together then the area was determined by an *Image-Pro Plus* threshold option (Figure D4a.). When the image contained blurry sections, using the threshold option made the colony area bigger than its actual size with an expanded diameter. To compensate the image analyses error, multiple diameter measurements were taken of the filament from the

original image (d) and processed image (d'). The averaged values of d ($\bar{d}$) were used to determinate the length of the filament (Equation. D4), while the average diameter of the original image($\bar{d}$) was used to calculate cross sectional area (Equation. D5):

$$L = \frac{A}{\bar{d}'} \quad \text{(Equation D4)}$$

where: $\bar{d}'$ –mean diameter (μm),
A –area (μm²) and
L – length (μm)

$$Ac = \frac{\pi}{4} \times \bar{d}^2 \quad \text{(Equation D5)}$$

where: Ac –cross sectional area (μm²) and
$\bar{d}$ –mean diameter (μm²)

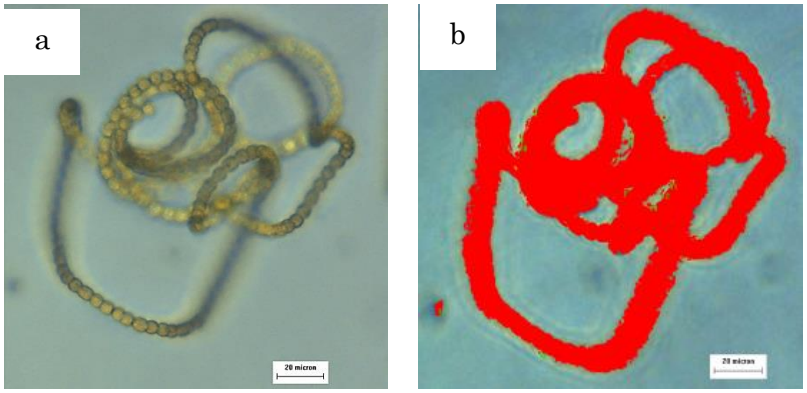


Figure D1. *Anabaena* sp. (a) filament, and (b) applied count/size command for area determination

Then the unit biovolume was calculated using Equation D6:

$$V_u = Ac \times L \quad \text{(Equation D6)}$$

where: V_u – unit biovolume (μm³),
Ac –cross sectional area (μm²) and
L – length (μm)

If the filament measurements were interrupted by other objects like cells, dirt or grid on the counting chamber, the subarea of the filament was used for biovolume estimation.

D4. Method III: Biovolume Based on Commonly Accepted Geometry

D4.1. Biovolume determination

Phytoplankton biovolume was calculated by applying formulas representing the closest approximation of similar geometric shapes. The shapes assigned for calculating cell biovolume are shown on Table D1. The shapes assigned for each genera used in this study are Included in Table D2. All required measurements of different shapes, such as diameter (d), width (w) and length (L) were taken from the image.

Table D1. Basic geometric shapes and formulas for biovolume calculations

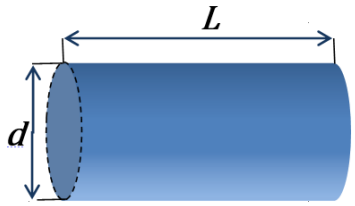
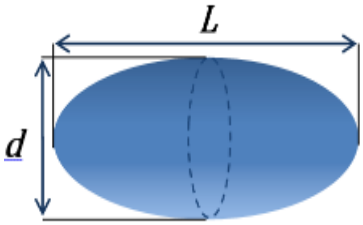
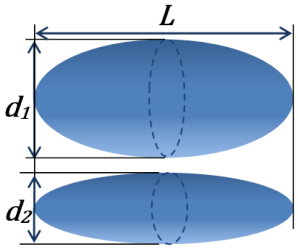
geometric shape	volume formula
cylinder 	$V = \frac{\pi}{4} \times d^2 \times L$ where: d – diameter L – length
prolate spheroid 	$V = \frac{\pi}{6} \times d^2 \times L$ where: d –diameter L – length
flattaned speroid 	$V = \frac{\pi}{6} \times d_1 \times d_2 \times L$ where: d_1 – large diameter d_2- small diameter L – length

Table D1: Basic geometric shapes and formulas for biovolume calculations (continued)

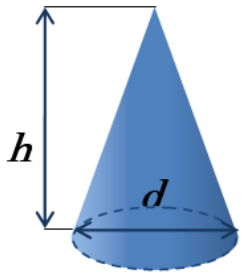
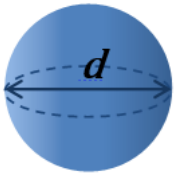
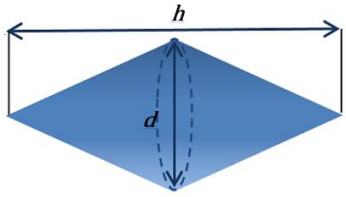
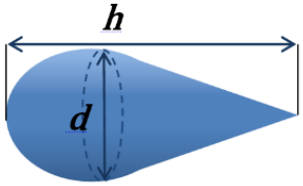
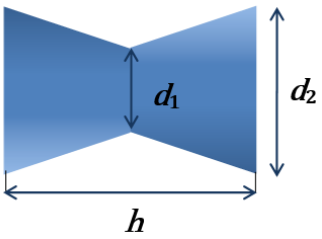
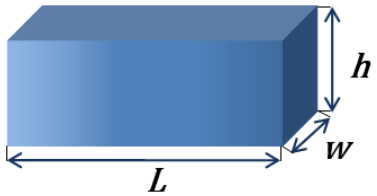
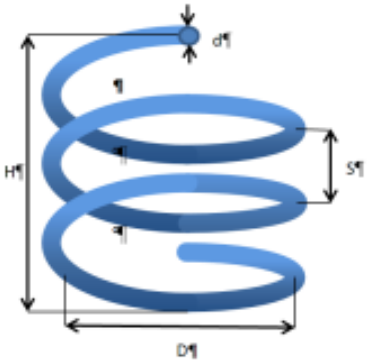
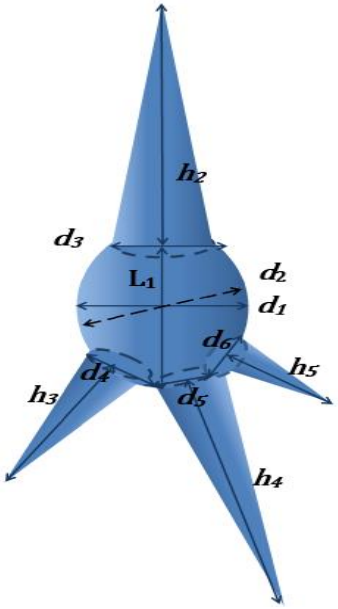
geometric shape	volume formula
cone 	$V = \frac{\pi}{12} \times d^2 \times h$ where: d – diameter h – height
sphere 	$V = \frac{\pi}{6} \times d^3$ where: d – diameter
2 cones 	$V = \frac{\pi}{12} \times d^2 \times h$ where: d – diameter h – height
cone+half sphere 	$V = \frac{\pi}{12} \times d^2 \times h$ where: d – diameter h – height
2 truncated cones 	$V = \frac{\pi}{6} \times h \times (d_1^2 + d_1 \times d_2 + d_2^2) \times h$ where: d_1 – small diameters d_2 – large diameters h – height
pararlelepiped 	$V = L \times w \times h$ where: L – length w– width h – height

Table D1: Basic geometric shapes and formulas for biovolume calculations (continued)

geometric shape	volume formula
coil 	$V = \left(\frac{\pi}{4} \times d^2\right) \times \sqrt{(\pi \times D \times n)^2 \times (s \times n)^2}$ $\underbrace{\qquad\qquad\qquad\qquad}_{L}$ **where:** D – diameter of the coil d – diameter of a filament s – spacing n – number of turns H – length of a coil L – length of filament
	$V = \frac{\pi}{6} \times d_1 \times d_2 \times L + \frac{\pi}{12} \times d_3^2 \times h + \bar{V}$ **where:** d_1 – large diameter of the spheroid d_2- small diameter of the spheroid L – length of the spheroid d_3– diameter of the upper cone h_1 – height of the upper come $\bar{V}$ – average biovolume of the small cones

Sometimes the shape could not be accurately applied, for example, the cells *Pandorina* sp.(Figure D5) the cells are approximately conical in shape; however, because the cell is rounded at the bottom, the accurate diameter is difficult to estimate.

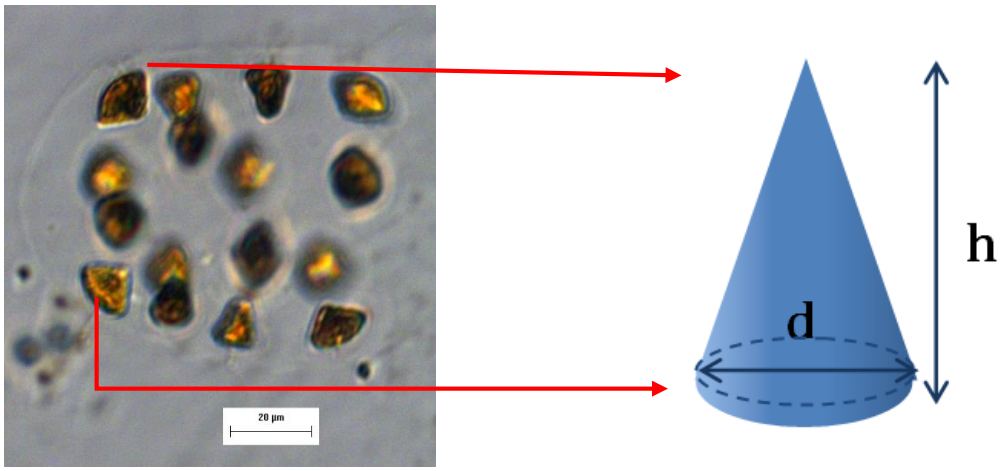


Figure D5. *Pandorina* sp. and geometric shape approximation, where d-diameter and h - high of the cone.

In such a case, it was assumed that the cross sectional area (A_c) of the original cells was a triangle with a cross sectional area A', where A'= A. Accordingly, the height and the diameter of the A' are h' and d', where $h=h'$ and $d \neq d'$, respectively (Figure D6).

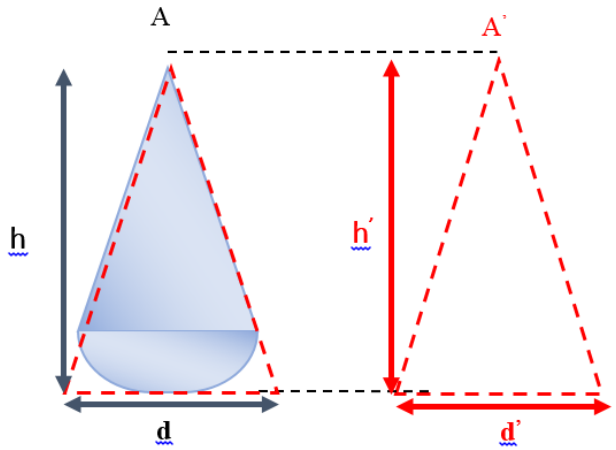


Figure D2. The geometrical shape approximation on one cell from the colony.

The diameter d′was estimated using the cross sectional Area-A' and manually measured h' using Equation D7:

$$d' = \frac{A}{h} = \frac{A'}{h'} \qquad \text{(EquationD7)}$$

Then the cell biovolume was calculated using the formula for Volume of a cone Equation. D8:

$$V_u = \frac{\pi}{12} \times d'^2 \times h' \qquad \text{(Equation D8)}$$

where: V_u – unit biovolume (μm^3)
d' - assumed diameter (μm)
h' – assumed height (μm)

When the width (w) of some species, such as *Asterionella sp.* (Figure D7) varied, w was determined from the area and the length of the cell (Equation. D9):

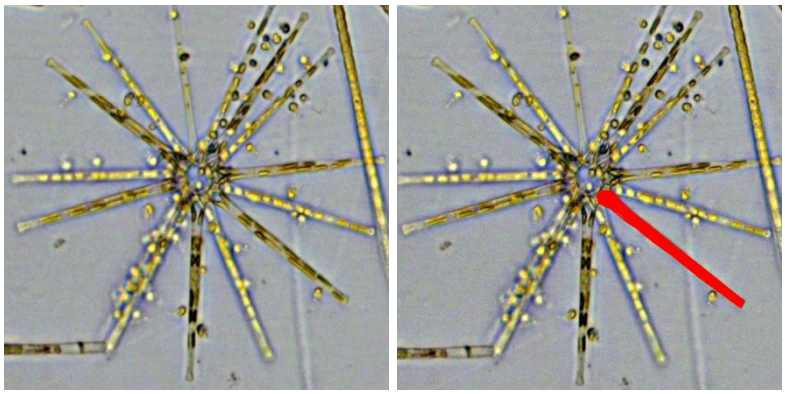


Figure D3. Asterionella sp. and applied threshold option for area determination of one cell

$$\overline{w} = \frac{A}{L} \qquad \text{(Equation D9)}$$

where: $\overline{w}$ – mean width (μm),
A – area (μm^2)
L – length (μm)

For those forms which are loricate (e.g., *Dinobryon*) the active portion, i.e. protoplast, was measured (Figure D8).

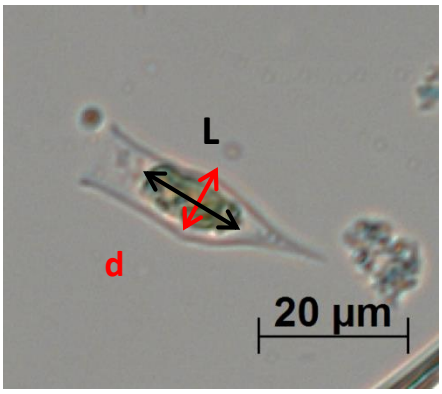


Figure D4. *Dinobryon* sp., where diameter and L-length.

If the cells were organized in colonies, then the unit volume of a colony was determined by multiplying the cell biovolume by number of cells in the colony (Equation. D10).

$$V_u = V_{cell} \times n \qquad \text{(Equation D10)}$$

where: V_u – unit biovolume (μ^3),
Vcell – Volume of one cell (μ^2) and
n – number of cells

The number of cells in the colony for species such as *Pandorina* and *Eudorina* was easily counted; however, for colonies of *Microcystis* sp. and *Gamphoshpaeria* sp. that consist of thousands of cells, simple counts were not possible. When cells in the colony could not be counted, the number of cells was determined by dividing the area of the colony filled with cells by the area of one cell. The area of the colony filled with cells was determined using the *Image-Pro Plus* threshold tool. Determining the area of a cell required several dimensional measurements that depended on the geometric shape of the cell. If the cell was spherical, such as *Microcystis* sp., the diameter of multiple cells was measured and then averaged. Then the area of a spherical cell was calculated by Equation. D11:

$$A_{cell} = \frac{\pi}{4} \times \bar{d}^3 \qquad \text{(Equation D11)}$$

where: A_{cell} –area of one cell(μm^2),
$\bar{d}$- diameter of a cell (µm)

D5. Determine the Number of Measured unit

If the number of units were more than 20 per sample, not more than 30 units of phytoplankton were measured. If the number of units was less than 20 per sample, at least 10 randomly selected units or all clear pictures of the unit was measured. When fewer than 10 units were present, such as for rare species, all units were measured as they occurred.

D6. Calculate the Biovolume of a Unit in the Sample

The calculated unit volume was averaged and multiplied by the number of the counted units (cells, filaments or colonies) to calculate the biovolume of the species in the sample (Equiation D12).

$$BV = \overline{V_u} \times n_u \qquad \text{(Equation D12)}$$

where: BV – biovolume of the unit in a sample (μm^3),
$\overline{Vu}$ – averaged unit volume(μm^3)
n_u – number of unit (cell, colony or filament)

D7. Phytoplankton abundance and biovolume 2010 and 2011.

D7.1. Phytoplankton abundance and biovolume, Site A (2010)

Table D2. Phytoplankton counts and biovolume, Site A (6/4/2010)

Class/Genus	Biovolume per unit μm^3	water depth								Depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	$\mu m^3/L$
Bacillariophyceae										
Asterionella sp. *	1.01E+03	80	4.64E+06	50	2.93E+06	14	9.33E+05			1.63E+06
Aulacoseira sp.*	1.36E+03			12	9.53E+05	26	2.34E+06	31	3.40E+06	1.77E+06
Cocconeis sp.*	4.93E+03					1	3.26E+05	1	3.96E+05	1.99E+05
Fragilaria sp.*	1.88E+03	3480	3.76E+08	2480	2.71E+08	3560	4.42E+08	2360	3.56E+08	3.35E+08
Navicula sp.*	9.97E+02	1	5.74E+04			1	6.60E+04			2.71E+04
Stephanodiscus sp.*	2.01E+04	30	3.48E+07	35	4.10E+07	35	4.66E+07	40	6.47E+07	4.47E+07
Chlorophyceae										
Closterium sp.*	1.09E+03					2	1.45E+05			3.62E+04
Coelastrum sp.**	1.25E+04					20	1.66E+07			4.14E+06
Characium sp.*	1.23E+03	1	7.07E+04							1.30E+04
Pediastrum sp.*	1.51E+04	2	1.74E+06	1	8.77E+05					2.63E+06
Staurastrum sp.*	6.77E+03					3	1.34E+06	1	5.45E+05	4.97E+05
Ankyra sp.*	1.01E+02	10	5.80E+04	10	5.86E+04					2.15E+04
Eudorina sp.**	9.09E+02					1	6.01E+04			1.50E+04
Cryptophyceae										
Cryptomonas sp.*	1.72E+03	3330	1.10E+09	4210	8.24E+08	3241	7.37E+08	80	2.19E+08	5.04E+08
Class Cyanobacteria										
Anabaena sp. ***	1.71E+04	2	1.97E+06	1	9.94E+05	1	1.13E+06	2	2.74E+06	9.45E+05
Dinophyceae										
Ceratium sp.*	8.31E+04	10	4.79E+07		0.00E+00	2	1.10E+07	5	3.34E+07	1.24E+07
Peridinium sp.*	1.29E+04	6	4.47E+06	9	6.78E+06					2.10E+06
Euglenophyceae										
Phacus sp.*	4.62E+04	1		1	2.69E+06					6.66E+05
Synurophyceae					0.00E+00					
Mallomonas sp.*	1.61E+03			1	9.37E+04	2	2.13E+05			1.13E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D3. Phytoplankton counts and biovolume, Site A (6/18/2010)

Class/Genus	Biovolume per unit µm³	water depth										Depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 1.5m from the bottom		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae												
Asterionella sp. *	1.01E+03	25	1.71E+06	35	3.21E+06	20	1.86E+06	26	2.34E+06	50	4.35E+06	2.58E+06
Aulacoseira sp.*	1.36E+03	20280	1.88E+09	14520	1.80E+09	9640	1.21E+09	18520	2.25E+09	6440	7.58E+08	1.59E+09
Cocconeis sp.*	4.93E+03	2	6.70E+05									8.66E+04
Cymbella sp.*	9.01E+03					1	8.33E+05					2.37E+05
Fragilaria sp.*	1.88E+03	63920	8.14E+09	55760	9.51E+09	56640	9.82E+09	52840	8.84E+09	33480	5.42E+09	8.53E+09
Navicula sp.*	9.97E+02	1	6.77E+04	2	1.81E+05	3	2.76E+05	3	2.67E+05	2	1.72E+05	2.16E+05
Stephanodiscus sp*	2.01E+04	15	2.05E+07	15	2.74E+07	6	1.12E+07	1	1.79E+06			9.88E+06
Unkn. Diatoms*	1.10E+04			1	9.99E+05							1.29E+05
Chlorophyceae												
Closterium sp.*	1.09E+03	10	7.43E+05	6	5.97E+05	24	2.43E+06	5	4.88E+05	6	5.67E+05	1.10E+06
Coelastrum sp.*	1.25E+04	15	1.27E+07	13	1.48E+07			1	1.12E+06			3.88E+06
Characium sp.*	1.23E+03	1	8.33E+04					1	1.09E+05			4.19E+04
Oocystis sp.*	1.59E+03					4	5.87E+05	1	1.42E+05	4	5.49E+05	3.02E+05
Pediastrum sp.*	1.51E+04	2	2.05E+06	3	4.11E+06	10	1.39E+07	3	4.03E+06			5.90E+06
Scenedesmus sp.*	1.89E+02	8	1.03E+05			10	1.75E+05	4	6.75E+04	8	1.31E+05	1.05E+05
Staurastrum sp.*	6.77E+03	1	4.60E+05	15	9.24E+06	5	3.13E+06	8	4.83E+06	6	3.51E+06	4.12E+06
Ankyra sp.*	1.01E+02	10	6.83E+04			15	1.39E+05	15	1.35E+05	10	8.69E+04	1.02E+05
Elakatothrix sp.*	3.98E+02											
Cryptophyceae												
Cryptomonas sp.*	2.37E+03	9560	2.54E+09	6560	2.31E+09	7280	2.04E+09	7000	2.59E+09	6640	1.53E+09	2.21E+09
Chrysophyceae												
Dinobryon sp.*	3.97E+02	30	8.08E+05	25	9.01E+05	20	7.33E+05	25	8.84E+05	15	5.14E+05	7.70E+05
Cyanophyceae												
Anabaena sp.*	2.76E+05	65	7.53E+07	75	1.16E+08	66	1.52E+08	35	9.94E+07	56	1.27E+08	1.18E+08
Dinophyceae												
Ceratium sp.*	8.31E+04	30	1.69E+08	32	2.42E+08	25	1.92E+08	15	1.11E+08	16	1.15E+08	1.59E+08
Peridinium sp.*	1.29E+04	9	7.90E+06	28	3.29E+07	10	1.19E+07	8	9.22E+06	15	1.67E+07	1.42E+07
Euglenophyceae												
Phacus sp.*	4.62E+04	1	3.14E+06									4.06E+05
Synurophyceae												
Mallomonas sp.*	1.61E+03	2	2.18E+05					1	1.43E+05	15	5.09E+07	8.85E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D4. Phytoplankton counts and biovolume, Site A (7/9/2010)

Class/Genus	Biovolume per unit μm^3	water depth								Depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	$\mu m^3/L$
Bacillariophyceae										
Asterionella sp. *	1.01E+03							8	5.91E+05	2.07E+05
Cocconeis sp.*	4.93E+03			2	7.98E+05			1	3.62E+05	2.92E+05
Fragilaria sp.*	1.88E+03	150	2.30E+07	250	3.80E+07	200	3.29E+07	300	4.13E+07	3.54E+07
Stephanodiscus sp.*	2.01E+04	10	1.64E+07	9	1.47E+07	9	1.59E+07	5	7.38E+06	1.27E+07
Chlorophyceae										
Closterium sp.*	6.12E+04	3	2.60E+05	6	5.32E+05	7	6.72E+05	7	1.38E+07	4.10E+07
Coelastrum sp. *	1.25E+04					1	1.10E+06			3.24E+05
Characium sp.*	1.23E+03	1	1.00E+05	1	9.93E+04	1	1.08E+05			6.70E+04
Oocystis sp.*	1.59E+03			1	1.29E+05					2.66E+04
Pediastrum sp.*	1.51E+04			1	1.22E+06	2	2.64E+06			1.03E+06
Scenedesmus sp.*	1.89E+02	4	6.18E+04							9.13E+03
Staurastrum sp.*	6.77E+03	5	2.77E+06	2	1.10E+06	1	5.94E+05	1	4.97E+05	9.85E+05
Quadrigulla sp.*	2.75E+02							7	1.41E+05	4.95E+04
Ankyra sp.*	1.01E+02	6	4.93E+04	10	8.14E+04	5	4.41E+04	3	2.21E+04	4.49E+04
Eudorina sp.*	9.09E+02			1	7.36E+04					1.52E+04
Cryptophyceae										
Cryptomonas sp.	1.61E+03	15080	3.71E+09	9720	2.03E+09	3040	7.11E+08	720	1.32E+08	1.22E+09
Cyanophyceae										
Anabaena sp.***	2.76E+05	16	2.76E+08	16	6.40E+07	21	1.68E+08	10	2.03E+08	1.75E+08
Aphanizomenon sp.***	7.21E+03	70	4.12E+07	70	4.09E+07	55	3.48E+07	45	2.38E+07	3.31E+07
Gomphosphaeria sp.**		6	1.72E+07	3	8.54E+06			3	7.74E+06	7.02E+06
Dinophyceae										
Ceratium sp.*	8.31E+04	6	4.07E+07	4	2.69E+07	3	2.18E+07	3	1.83E+07	2.44E+07
Peridinium sp.*	1.29E+04	2326	2.45E+09	2885	3.02E+09	1563	1.77E+09	763	7.21E+08	1.76E+09
Synurophyceae	4.20E+04				3.40E+06					7.02E+05
Mallomonas sp.*	1.61E+03	20	2.63E+06	15	1.95E+06					7.91E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D5. Phytoplankton counts and biovolume, Site A (7/23/2010)

date 7/23/2010 Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										
Aulacoseira sp.*	1.36E+03	45	4.17E+06	13	1.80E+06	40	6.23E+06	37	5.27E+06	4.99E+06
Cocconeis sp.*	4.93E+03			1	5.00E+05			5	2.57E+06	1.19E+06
Cymbella sp.*	9.01E+03			1	9.15E+05	6	6.18E+06			2.07E+06
Fragilaria sp.*	1.88E+03	1240	1.58E+08	550	1.05E+08	960	2.06E+08	240	4.70E+07	1.17E+08
Gomphonema sp.*	7.83E+03			1	7.94E+05	7	6.26E+06			2.08E+06
Stephanodiscus sp.*	2.01E+04	30	4.10E+07	21	4.29E+07	16	3.68E+07	11	2.31E+07	3.21E+07
Synedra sp.*	1.42E+04							1	1.48E+06	6.50E+05
Chlorophyceae										
Closterium sp.*	1.09E+03	5	3.72E+05	2	2.22E+05	5	6.25E+05	6	6.86E+05	1.06E+06
Closterium sp. 2*	1.05E+03	5	3.55E+05	2	2.12E+05	6	7.17E+05	4	4.37E+05	
Coelastrum sp. *	1.07E+03	10	7.27E+05	4	4.34E+05	11	1.34E+06	10	1.12E+06	
Characium sp.*	1.23E+03					6	8.41E+05			2.65E+05
Oocystis sp.*	1.59E+03							1	1.66E+05	7.27E+04
Pediastrum sp.**	1.51E+04	3	3.07E+06	2	3.06E+06					7.55E+05
Scenedesmus sp.*	1.89E+02	4	5.14E+04							5.99E+03
Ankyra sp.*	1.01E+02			1	1.02E+04					1.33E+03
Elakatothrix sp.*	3.98E+02			4	1.61E+05					2.10E+04
Eudorina sp.*	9.09E+02			1		8	8.31E+05	1	9.49E+04	3.03E+05
Cryptophyceae										
Cryptomonas sp.	1.61E+03	3280	7.19E+08	2600	7.93E+08	2000	6.00E+08	1960	5.13E+08	6.01E+08
Cyanophyceae										
Anabaena sp. ***	2.76E+05	5	4.10E+07	2	1.09E+08	2	1.22E+08	7	6.66E+07	8.66E+07
Aphanizomenon sp.***	7.21E+03	720	3.53E+08	680	4.98E+08	240	1.98E+08	720	5.42E+08	4.06E+08
Microcystis sp.**	1.80E+05	1	1.22E+07	1	1.83E+07	5	1.03E+08	6	1.13E+08	8.57E+07
Oscillatoria sp.***	1.52E+04					9	1.56E+07			4.92E+06
Lyngbya sp.***	2.16E+04	1	1.46E+06	1				1	2.25E+06	1.16E+06
Gomphosphaeria sp.**	3.51E+04			1	3.57E+06	1	4.01E+06			1.73E+06
Dinophyceae										
Ceratium sp.*	8.31E+04	150	8.46E+08	250	2.11E+09	190	1.80E+09	100	8.68E+08	1.32E+09
Peridinium sp.*	2.74E+04	10205	9.70E+09	12220	1.78E+10	10150	1.65E+10	7790	1.13E+10	1.36E+10
Euglenophyceae										
Phacus sp.*	4.62E+04	1	3.14E+06							8.07E+04

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D6. Phytoplankton counts and biovolume, Site A (8/6/2010)

Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm3/L	units/ml	µm3/L	units/ml	µm3/L	units/ml	µm3/L	µm3/L
Bacillariophyceae										
Aulacoseira sp.*	1.36E+03	18	2.74E+06	4	7.01E+05	14	1.67E+06	5	7.39E+05	1.31E+06
Fragilaria sp.*	1.88E+03	55	1.15E+07	60	1.45E+07	70	1.15E+07	98	1.99E+07	1.51E+07
Stephanodiscus sp.*	2.01E+04	6	1.35E+07	4	1.03E+07	5	8.78E+06	10	2.18E+07	1.44E+07
Chlorophyceae										
Closterium sp.*	6.12E+04	5	6.11E+05	11	1.54E+06	10	9.51E+05	5	5.93E+05	8.90E+05
Characium sp.*	1.23E+03	2	2.74E+05			1	1.07E+05			7.28E+04
Oocystis sp.*	1.59E+03							4	6.89E+05	2.45E+05
Pediastrum sp.**	1.51E+04	1	1.68E+06	1	1.94E+06	3	3.94E+06			1.80E+06
Staurastrum sp.*	6.77E+03	6	4.54E+06	2	1.74E+06					1.03E+06
Eudorina sp.*	9.09E+02			1	1.17E+05	1	7.94E+04			4.66E+04
Cryptophyceae										
Cryptomonas sp.*	1.61E+03	9320	1.53E+09	8080	8.66E+08	8360	1.25E+09	2720	3.78E+08	9.04E+08
Cyanophyceae										
Anabaena sp. ***	2.76E+05	81	2.12E+08	81	2.44E+08	81	1.66E+08	3	5.55E+06	1.31E+08
Aphanizomenon sp.***	7.21E+03	200	1.61E+08	120	1.11E+08	280	1.76E+08	120	9.39E+07	1.32E+08
Microcystis sp.**	1.80E+05	2	4.02E+07	3	6.95E+07	2	3.15E+07	3	5.86E+07	5.00E+07
Lyngbya sp.***	2.16E+04	25	6.02E+07	35	9.71E+07	30	5.65E+07	7	1.64E+07	5.08E+07
Gomphosphaeria sp.**	3.51E+04	1	3.92E+06	6	2.71E+07	2	6.14E+06	2	7.62E+06	1.05E+07
Dinophyceae										
Ceratium sp.*	8.31E+04	55	5.10E+08	165	1.76E+09	180	1.31E+09	38	3.42E+08	9.34E+08
Peridinium sp.*	2.74E+04	2687.5	3.90E+09	4072.5	6.82E+09	3572.5	4.06E+09	2165	3.05E+09	4.23E+09
Euglenophyceae										
Lepocinclis sp.*	1.12E+04							1	1.21E+06	4.31E+05
Synurophyceae										
Mallomonas sp.*	1.61E+03			1	2.07E+05					4.11E+04

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D7. Phytoplankton counts and biovolume, Site A (8/20/2010)

Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										
Aulacoseira sp.*	1.36E+03	22	3.68E+06	54	8.01E+06	14	2.27E+06	29	3.14E+06	3.59E+06
Cocconeis sp.*	4.93E+03	1	6.06E+05	1	5.37E+05					1.46E+05
Fragilaria sp.*	1.88E+03	80	1.84E+07	120	2.45E+07	171	3.81E+07	200	2.98E+07	3.03E+07
Stephanodiscus sp.*	2.01E+04	4	9.88E+06	13	2.85E+07	20	4.77E+07	52	8.31E+07	5.57E+07
Chlorophyceae										
Closterium sp. 2*	1.05E+03					1	1.24E+05			3.90E+04
Characium sp.*	1.23E+03	2	3.01E+05	2	2.67E+05	1	1.46E+05	7	6.82E+05	4.11E+05
Pediastrum sp.**	1.51E+04	1	1.85E+06	1	1.64E+06	3	5.36E+06	4	4.79E+06	4.18E+06
Scenedesmus sp.*	1.89E+02			8	1.65E+05					2.24E+04
Staurastrum sp.*	6.77E+03	2	1.66E+06	1	7.37E+05	2	1.61E+06	3	1.61E+06	1.50E+06
Ankyra sp.*	1.01E+02	10	1.24E+05	15	1.64E+05					3.73E+04
Elakatothrix sp.*	3.98E+02	2	9.77E+04							1.19E+04
Cryptophyceae										
Cryptomonas sp.*	1.61E+03	10920	8.53E+08	5960	4.10E+08	5440	6.81E+08	7760	6.13E+08	6.36E+08
Cyanophyceae										
Anabaena sp. ***	2.76E+05	3	6.99E+07	2	6.01E+07	5	3.18E+08	3	1.28E+08	1.71E+08
Aphanizomenon sp.***	7.21E+03	280	2.48E+08	160	1.26E+08	160	1.37E+08	480	2.75E+08	2.08E+08
Microcystis sp.**	1.80E+05	1	2.21E+07	6	1.18E+08	4	8.56E+07	7	1.00E+08	8.85E+07
Lyngbya sp.***	2.16E+04	10	2.65E+07	6	1.41E+07	15	3.84E+07	10	1.71E+07	2.45E+07
Gomphosphaeria sp.**	3.51E+04	15	6.47E+07	14	5.36E+07					1.51E+07
Dinophyceae										
Ceratium sp.*	8.31E+04	85	8.67E+08	65	5.88E+08	77	7.60E+08	69	4.55E+08	6.19E+08
Peridinium sp.*	2.74E+04	3495	5.60E+09	5085	7.17E+09	4960	7.61E+09	7370	7.59E+09	7.30E+09
Euglenophyceae										
Lepocinclis sp.*	1.12E+04			1	1.22E+06	1	1.33E+06			5.82E+05
Phacus sp.*	4.62E+04							1	3.67E+06	1.57E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D8. Phytoplankton counts and biovolume, Site A (9/3/2010)

Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										
Aulacoseira sp.*	1.36E+03	36	4.70E+06	12	2.12E+06	25	3.36E+06	13	2.21E+06	2.91E+06
Cocconeis sp.*	4.93E+03	1	4.72E+05	2	1.28E+06	2	9.74E+05			6.14E+05
Cymbella sp.*	9.01E+03			1	1.17E+06					2.82E+05
Fragilaria sp.*	1.88E+03	1880	3.38E+08	1560	3.80E+08	1960	3.63E+08	1200	2.81E+08	3.34E+08
Navicula sp.*	9.97E+02			1	1.29E+05					3.12E+04
Stephanodiscus sp.*	2.01E+04	12	2.31E+07	13	3.39E+07	16	3.18E+07	10	2.51E+07	2.83E+07
Chlorophyceae										
Closterium sp.*	1.09E+03	25	2.62E+06	15	2.13E+06	20	2.16E+06	15	2.05E+06	2.20E+06
Coelastrum sp. *	1.25E+04					5	6.18E+06	2	3.12E+06	2.47E+06
Characium sp.*	1.23E+03	3	3.52E+05	1	1.59E+05	3	3.63E+05	3	4.59E+05	3.45E+05
Oocystis sp.*	1.59E+03	1	1.52E+05			3	4.70E+05	9	1.78E+06	7.55E+05
Pediastrum sp.**	1.51E+04	1	1.44E+06	2	3.91E+06	1	1.49E+06			1.54E+06
Scenedesmus sp.*	1.89E+02	4	7.25E+04			4	7.47E+04	4	9.44E+04	6.32E+04
Staurastrum sp.*	6.77E+03	7	4.54E+06	11	9.67E+06	16	1.07E+07	12	1.01E+07	9.10E+06
Quadrigulla sp.*	2.75E+02			3	1.07E+05			4	1.37E+05	7.36E+04
Eudorina sp.*	9.09E+02	1	8.71E+04	1	1.18E+05					4.48E+04
Cryptophyceae										
Cryptomonas sp.*	1.61E+03	3360	8.49E+08	5320	1.39E+09	4400	1.17E+09	4240	1.50E+09	1.28E+09
Cyanophyceae										
Anabaena sp. ***	2.76E+05	4	1.55E+08	3	1.41E+08	9	2.20E+08	1	2.13E+06	1.13E+08
Aphanizomenon sp.***	7.21E+03	240	1.66E+08	160	1.50E+08	80	5.70E+07	120	1.08E+08	1.17E+08
Microcystis sp.***	1.80E+05	2	3.45E+07			3	5.34E+07	2	4.50E+07	3.40E+07
Oscillatoria sp.***	1.52E+04					1	1.50E+06			3.35E+05
Lyngbya sp.***	2.16E+04	2	4.13E+06	2	5.60E+06					2.12E+06
Gomphosphaeria sp.*	3.51E+04	8	2.69E+07	8	3.65E+07	9	3.12E+07	4	1.75E+07	2.69E+07
Dinophyceae										
Ceratium sp.*	8.31E+04	340	2.71E+09	310	3.34E+09	320	2.63E+09	310	3.21E+09	3.02E+09
Peridinium sp.*	2.74E+04	6602	8.18E+09	5806	9.76E+09	8615	1.10E+10	5520	8.90E+09	9.45E+09
Synurophyceae										
Mallomonas sp.*	1.61E+03	1	1.54E+05			1	1.59E+05	2	4.01E+05	2.04E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D9. Phytoplankton counts and biovolume, Site A (9/17/2010)

Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										
Cymbella sp.*	9.01E+03	1	1.08E+06							1.68E+05
Fragilaria sp.*	1.88E+03	1680	3.78E+08	1280	2.74E+08	2880	6.72E+08	680	1.46E+08	3.44E+08
Stephanodiscus sp.*	2.01E+04	15	3.62E+07	10	2.30E+07	18	4.50E+07	10	2.31E+07	3.09E+07
Chlorophyceae										
Closterium sp.*	1.09E+03	36	4.73E+06	45	5.62E+06	38	5.17E+06	18	2.26E+06	4.04E+06
Closterium sp. 2*	1.05E+03							1	1.20E+05	4.72E+04
Coelastrum sp. *	1.25E+04	1	1.50E+06			5	7.78E+06	2	2.87E+06	3.40E+06
Characium sp.*	1.23E+03	3	4.42E+05	1	1.40E+05					9.52E+04
Oocystis sp.*	1.59E+03	1	1.91E+05	3	5.44E+05	1	1.98E+05	1	1.82E+05	2.56E+05
Scenedesmus sp.*	1.89E+02	4	9.08E+04							1.41E+04
Staurastrum sp.*	6.77E+03	1	8.13E+05			7	5.90E+06	7	5.44E+06	3.82E+06
Quadrigulla sp.*	2.75E+02	4	1.32E+05					2	6.31E+04	4.54E+04
Ankyra sp.*	1.01E+02	38	4.59E+05	29	3.33E+05	18	2.25E+05			1.93E+05
Cryptophyceae										
Cryptomonas sp.	1.61E+03	3760	1.25E+09	4760	1.39E+09	3920	1.30E+09	3840	8.60E+08	1.14E+09
Cyanophyceae										
Anabaena sp.***	5.35E+05	3	1.93E+08	6	3.67E+08	6	3.99E+08	5	3.07E+08	3.25E+08
Aphanizomenon sp.***	7.21E+03	50	4.33E+07	50	5.76E+06	50	4.49E+07	50	4.14E+07	3.59E+07
Microcystis sp.***	1.80E+05	1	2.16E+07			2	4.48E+07			1.51E+07
Oscillatoria sp.***	1.52E+04			3	5.20E+06					9.80E+05
Lyngbya sp.***	2.16E+04	1	2.59E+06	1	2.46E+06	3	8.05E+06	2	4.95E+06	4.93E+06
Gomphosphaeria sp.*	3.51E+04	25	1.05E+08	5	2.01E+07	12	5.24E+07			3.40E+07
Dinophyceae										
Ceratium sp.*	8.31E+04	100	9.97E+08	100	9.49E+08	100	1.03E+09	50	4.77E+08	7.93E+08
Peridinium sp.*	2.74E+04	7880	1.22E+10	7802	1.15E+10	6600	1.06E+10	6560	9.74E+09	1.07E+10
Gymnodinium sp. *	1.97E+03			4	8.98E+05			2	4.52E+05	3.47E+05
Euglenophyceae										
Lepocinclis sp.*	1.12E+04			1	1.28E+06					2.40E+05
Synurophyceae										
Mallomonas sp.*	1.61E+03	4	7.72E+05	5	9.18E+05	6	1.20E+06	2	3.69E+05	7.53E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D10. Phytoplankton counts and biovolume, Site A (10/1/2010)

Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										
Cymbella sp.*	9.01E+03							1	7.99E+05	2.68E+05
Fragilaria sp.*	1.88E+03	3960	7.16E+08	4240	8.20E+08	5600	9.03E+08	6480	1.08E+09	9.10E+08
Stephanodiscus sp.*	2.01E+04	35	6.78E+07	25	5.19E+07	20	3.46E+07	30	5.35E+07	5.07E+07
Cyclotella sp.*	8.56E+02			2	1.77E+05					4.16E+04
Chlorophyceae										
Closterium sp.*	1.07E+03	15	1.58E+06	22	2.47E+06	16	1.51E+06	12	1.16E+06	1.63E+06
Coelastrum sp. *	1.25E+04			3	3.87E+06	1	1.08E+06			1.19E+06
Characium sp.*	1.23E+03							2	2.18E+05	7.30E+04
Oocystis sp.*	1.59E+03			2	3.28E+05					7.72E+04
Pediastrum sp.**	1.51E+04							2	2.67E+06	8.97E+05
Scenedesmus sp.*	1.89E+02							4	6.71E+04	2.25E+04
Staurastrum sp.*	6.77E+03	4	2.61E+06	2	1.40E+06	3	1.75E+06	1	6.01E+05	1.43E+06
Quadrigula sp.*	2.75E+02	12	3.18E+05	10	2.83E+05	6	1.42E+05	8	1.95E+05	2.23E+05
Ankyra sp.*	1.01E+02	1	9.69E+03	25	2.59E+05			16	1.43E+05	1.11E+05
Elakatothrix sp.*	3.98E+02							4	1.41E+05	4.74E+04
Cryptophyceae										
Cryptomonas sp.*	4.19E+03	10800	1.08E+04	11360	1.14E+04	13640	1.36E+04	12840	1.28E+04	3.64E+09
Cyanophyceae										
Anabaena sp. ***	2.76E+05	2	2.66E+07	1	2.76E+07	3	2.45E+07	1	2.37E+07	5.07E+07
Aphanizomenon sp.***	7.21E+03	6	4.17E+06	7	5.21E+06	6	3.72E+06			2.90E+06
Oscillatoria sp.***	1.52E+04							2	2.69E+06	9.04E+05
Lyngbya sp.***	2.16E+04	9	1.87E+07	3	6.67E+06	7	1.30E+07	9	1.72E+07	1.39E+07
Gomphosphaeria sp.*	3.51E+04	10	3.39E+07	11	3.99E+07	12	3.63E+07	15	4.67E+07	4.02E+07
Dinophyceae										
Ceratium sp.*	8.31E+04	2	1.60E+07			1	7.15E+06			4.58E+06
Peridinium sp.*	2.74E+04	75	9.34E+07	65	8.67E+07	78	8.67E+07	88	1.01E+08	9.26E+07
Gymnodinium sp. *	1.97E+03							1	1.74E+05	5.86E+04

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D11. Phytoplankton counts and biovolume, Site A (10/1/2010)

date 10/1/2010 Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										
Aulacoseira sp.*	1.36E+03					10	1.23E+06	22	2.57E+06	1.22E+06
Cocconeis sp.*	4.93E+03			2	7.02E+05	1	4.45E+05			2.84E+05
Cymbella sp.*	9.01E+03					1	8.13E+05			2.36E+05
Fragilaria sp.*	1.88E+03	2840	3.74E+08	5400	7.21E+08	2320	3.93E+08	3440	5.53E+08	5.16E+08
Navicula sp.*	9.97E+02					1	8.99E+04			2.61E+04
Stephanodiscus sp.*	2.01E+04	35	4.94E+07	41	5.87E+07	43	7.80E+07	38	6.55E+07	6.51E+07
Cyclotella sp.*	8.56E+02	1	6.01E+04							9.21E+03
Chlorophyceae										
Closterium sp.*	1.09E+03	6	4.61E+05	5	3.89E+05	7	6.91E+05	12	1.13E+06	7.34E+05
Coelastrum sp. *	1.25E+04					4	4.51E+06			1.31E+06
Characium sp.*	1.23E+03					2	2.21E+05			6.41E+04
Scenedesmus sp.*	1.89E+02			4	5.39E+04					1.19E+04
Staurastrum sp.*	6.77E+03	2	9.51E+05			3	1.83E+06	5	2.90E+06	1.65E+06
Ankyra sp.*	1.01E+02	1	7.06E+03			1	9.07E+03			3.71E+03
Eudorina sp.*	9.09E+02					1	8.20E+04			2.38E+04
Cryptophyceae										
Cryptomonas sp.*	1611	5760	1.41E+09	7280	1.26E+09	3440	7.78E+08	4000	1.44E+09	1.2E+09
Cyanophyceae										
Anabaena sp.*	2.71E+05	8	4.05E+06	9	4.62E+06	7	5.22E+07	3	1.85E+06	1.74E+07
Lyngbya sp.***	2.16E+04	2	3.03E+06	1	1.53E+06			4	7.39E+06	3.28E+06
Gomphosphaeria sp.*	3.51E+04	23	5.67E+07	4	1.00E+07	4	1.27E+07	6	1.81E+07	2.06E+07
Dinophyceae										
Peridinium sp.*	1.29E+04					5	5831436	1	1107599	2.06E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

D7.2. Phytoplankton abundance and biovolume, Site A (2011)

Table D12. Phytoplankton counts and biovolume, Site A (6/30/2011)

Class/Genus	biovolume per unit µm³	water depth										depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 1.5m from the bottom		at the 0.5m from the bottom		
		units/ ml	µm³/L	units /ml	µm³/L	units/ ml	µm³/L	units/ ml	µm³/L	units/ ml	µm³/L	µm³/L
Bacillariophyceae												
Asterionella sp.*	1.1E+03	250	3.7E+07	250	3.4E+07	250	2.8E+07	250	3.6E+07	250	2.7E+07	3.2E+07
Cocconeis sp.*	3.7E+03			3	1.3E+06					1	3.3E+05	2.3E+05
Cymbella sp.*	7.7E+03					1	8.7E+05					2.8E+05
Fragilaria sp.*	1.8E+03	5650	1.2E+09	3895	7.9E+08	5000	1.0E+09	6000	1.4E+09	5350	9.3E+08	1.1E+09
Stephanodiscus sp.*	2.2E+04	9	2.4E+07	7	1.7E+07	6	1.5E+07	10	2.8E+07	5	1.0E+07	1.9E+07
Synedra sp.*	1.3E+04					2	3.0E+06					9.6E+05
Chlorophyceae												
Closterium sp.*	1.7E+03		2.2E+05			1	2.6E+05	1	1.6E+05	2	2.4E+05	1.8E+05
Coelastrum sp.*	6.3E+03		3.3E+06	5	3.7E+06	7	5.3E+06	1	7.0E+05			2.9E+06
Pediastrum sp. *	5.8E+04		1.3E+06		2.4E+06		3.6E+07					1.2E+07
Staurastrum sp.*	6.8E+03	1	8.1E+05	1	7.5E+05	1	7.7E+05	1	8.6E+05	1	6.4E+05	7.8E+05
Cryptophyceae												
Cryptomonas sp.*	4.4E+03	3808	7.6E+07	9244	1.3E+08	3793	1.3E+07	111	6.9E+06	20	6.6E+06	3.6E+07
Chrysophyceae												
Dinobryon sp.*	2.8E+02	35	1.2E+06	45	1.5E+06	29	2.0E+06	16	4.8E+05	8	1.8E+05	1.2E+06
Cyanophyceae												
Anabaena sp.***	8.6E+03	2	4.4E+05	1	2.0E+05			2	3.9E+06	6	8.7E+06	2.2E+06
Aphanizomenon sp.***	2.7E+03	8	2.6E+06	9	2.7E+06	3	9.3E+05	2	7.0E+05	6	1.6E+06	1.4E+06
Dinophyceae												
Ceratium sp.*	9.1E+04	10	1.1E+08	8	8.2E+07	5	6.3E+07	6	6.8E+07	5	4.2E+07	7.1E+07
Peridinium sp.*	3.4E+04	12	1.2E+08	9	8.5E+07	6	6.3E+07	6	6.8E+07	5	4.2E+07	7.2E+07

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D13. Phytoplankton counts and biovolume, Site A (7/13/2011)

date 7/13/2011 Class/Genus	biovolume per unit μm^3	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	$\mu m^3/L$
Bacillariophyceae										
Asterionella sp.*	1.12E+03			20	2.54E+06			8	9.22E+05	7.48E+05
Aulacoseira sp.*	1.22E+03			4	5.53E+05					8.12E+04
Cocconeis sp.*	9.34E+02	8	8.27E+05	7	7.33E+05	11	9.53E+05	2	1.93E+05	5.97E+05
Fragilaria sp.*	4.86E+06	159	3.57E+07	225	5.12E+07	150	2.78E+07	57	1.18E+07	2.56E+07
Navicula sp.*	1.07E+03	1	1.19E+05							1.36E+04
Stephanodiscus sp.*	1.27E+04	4	5.68E+06			4		4	5.23E+06	2.78E+06
Chlorophyceae										
Closterium sp.*	1.17E+03	4	6.37E+05	11	1.78E+06	7	6.37E+05	1	1.13E+05	5.90E+05
Coelastrum sp.*	7.11E+03	1	7.95E+05	5	4.03E+06	15	9.84E+06			3.94E+06
Characium sp.*	1.31E+03	1	1.52E+05	1	1.54E+05	10	1.74E+06	7	4.94E+05	8.20E+05
Pediastrum sp. *	1.64E+04	4	1.35E+07	2	6.83E+06	4	4.55E+06	6	4.19E+06	5.76E+06
Staurastrum sp.*	2.06E+04	1	7.58E+05	4	3.07E+06	5	3.12E+06	7	3.49E+07	1.58E+07
Quadrigulla sp.*	2.75E+02					18	4.57E+05			1.51E+05
Ankyra sp.*	1.48E+02	6	9.95E+04					1	1.53E+04	1.76E+04
Eudorina*	7.89E+03	1	8.83E+05	10	8.94E+06	3	2.18E+06			2.14E+06
Cryptophyceae										
Cryptomonas sp.*	2.49E+03	4900	5.89E+08	8350	3.65E+08	8100	4.47E+08	1350	1.32E+08	3.23E+08
Chrysophyceae										
Dinobryon sp.*	5.94E+02	25	1.66E+06	25	1.21E+06	15	8.21E+05	10	6.11E+05	8.89E+05
Cyanophyceae										
Anabaena sp.***	8.55E+05	61	1.23E+09	70	5.03E+08	30	8.18E+08	16	1.98E+08	5.66E+08
Aphanizomenon sp.***	2.75E+03	19850	6.10E+09	16500	5.14E+09	17400	4.41E+09	4700	1.33E+09	3.45E+09
Microcystis sp.**	7.35E+04			5	4.16E+07	3	2.03E+07	6	4.54E+07	3.14E+07
Dinophyceae										
Ceratium sp.*	9.19E+04	2	2.06E+07	1	1.04E+07	3	2.54E+07			1.23E+07
Peridinium sp.*	1.90E+04	8	1.06E+07	7	1.51E+07	31	6.91E+08	10	1.96E+07	2.40E+08

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D14. Phytoplankton counts and biovolume, Site A (7/20/2011)

date 7/20/2011 Class/Genus	biovolume per unit µm³	water depth										depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 1.5m from the bottom		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae												
Cocconeis sp.*	3.8E+03	5	2.2E+06	2	1.0E+06							4.0E+05
Fragilaria sp.*	1.5E+03	27	4.7E+06	30	6.0E+06	36	5.2E+06	38	5.9E+06	89	9.7E+06	6.2E+06
Navicula sp.*	9.3E+02	1	1.1E+05	1	1.2E+05					1	6.8E+04	4.3E+04
Stephanodiscus sp.*	2.1E+04									11	1.7E+07	2.6E+06
Synedra sp.*	1.2E+04	1	1.5E+06									1.3E+05
Chlorophyceae												
Closterium sp.*	6.9E+04	7	2.2E+06	2	2.2E+05			2	2.0E+07	1	5.9E+04	4.9E+06
Coelastrum sp.*	1.3E+04	1	1.5E+06									1.3E+05
Characium sp.*	1.3E+03	2	3.1E+05			1	1.3E+05			1	9.6E+04	8.4E+04
Pediastrum sp. *	1.8E+04	6	1.3E+07	7	1.7E+07	12	2.1E+07	8	1.5E+07	4	5.2E+06	1.6E+07
Staurastrum sp.*	6.8E+03					1	6.5E+05	1	7.1E+05	1	4.9E+05	4.6E+05
Pandorina sp.**	1.6E+03	10	1.9E+06	20	4.4E+06							1.0E+06
Ankyra sp.*	2.0E+02			10	2.7E+05	15	2.9E+05	8	1.7E+05	1	1.5E+04	1.9E+05
Cryptophyceae												
Cryptomonas sp.*	1.0E+03	4300	2.4E+08		2.0E+08	85	1.7E+07	45	7.9E+06	27	3.3E+06	6.8E+07
Chrysophyceae												
Dinobryon sp.*	3.3E+02							3	1.0E+05			2.4E+04
Cyanophyceae												
Anabaena sp.***	4.6E+05	74	8.5E+08		1.1E+09	3	3.9E+08	8	5.7E+08			5.6E+08
Aphanizomenon sp.***	2.7E+03	39400	1.2E+10		7.8E+09	12500	3.2E+09	9200	2.7E+09	1800	3.8E+08	4.4E+09
Microcystis sp.**	7.0E+04	6	4.9E+07		5.6E+07	4	2.7E+07	2	1.5E+07			2.7E+07
Gomphosphaeria sp.*	1.5E+04	3	5.4E+06		4.1E+06	5	7.4E+06	1				3.7E+06
Dinophyceae												
Ceratium sp.*	9.7E+04	14	1.6E+08		2.6E+08	1	9.3E+06	1	1.0E+07			6.9E+07
Peridinium sp.*	2.8E+04	309	5.2E+08		6.8E+08	15	2.0E+07	10	1.4E+07	3	3.0E+06	1.9E+08
Euglenophyceae												
Lepocinclis sp.*	1.8E+03			133	2.4E+05							4.5E+04
Phacus sp.*	2.3E+04			133	3.1E+06							5.8E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D15. Phytoplankton counts and biovolume, Site A (7/27/2011)

date 7/27/2011 Class/Genus	biovolume per unit µm³	water depth										depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 1.5m from the bottom		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae												
Aulacoseira sp.*	1.4E+03					2	2.6E+05					9.3E+04
Cocconeis sp.*	5.6E+03	6	4.1E+06	3	2.1E+06	22	1.1E+07	3	1.6E+06	3	1.6E+06	5.4E+06
Fragilaria sp.*	1.2E+03	18	2.6E+06	20	3.0E+06	52	5.8E+06	33	3.8E+06			3.7E+06
Stephanodiscus sp.*	2.1E+04					1	2.0E+06					6.9E+05
Cyclotella sp.*	8.6E+02					1	8.0E+04					2.8E+04
Chlorophyceae												
Closterium sp.*	1.0E+03	4	5.1E+05	3	3.9E+05	3	2.9E+05	2	2.0E+05	1	9.8E+04	2.9E+05
Coelastrum sp.*	1.2E+04	5	7.4E+06	3	4.6E+06	2	2.3E+06					2.5E+06
Characium sp.*	1.4E+03					15	1.9E+06					6.8E+05
Oocystis sp.*	1.5E+03	1	1.8E+05									1.5E+04
Pediastrum sp. *	1.3E+04	6	9.3E+06	15	2.4E+07	6	7.1E+06	2	2.5E+06	1	1.2E+06	9.3E+06
Scenedesmus sp.*	1.4E+02			8	1.4E+05							3.2E+04
Pandorina sp.**	4.3E+03	1	5.2E+05	5	2.7E+06							6.5E+05
Cryptophyceae												
Cryptomonas sp.*	3.9E+03	1050	3.9E+08	550	3.6E+08	26	1.5E+07					1.2E+08
Cyanophyceae												
Anabaena sp.***	4.3E+05	19	9.5E+08	70	2.6E+09	52	1.8E+09	2	8.6E+05	7	2.9E+06	1.3E+09
Aphanizomenon sp.***	2.0E+03	34250	8.3E+09	34500	8.6E+09	11750	2.2E+09	6214	1.2E+09	2200	4.1E+08	3.7E+09
Microcystis sp.**	1.7E+05	15	3.2E+08	23	5.1E+08	2	3.3E+07					1.5E+08
Lyngbya sp.***	7.7E+03			1	9.7E+05							2.2E+05
Gomphosphaeria sp.*	1.5E+04					1	1.4E+06	1	1.5E+06			8.2E+05
Dinophyceae												
Ceratium sp.*	8.2E+04	10	1.0E+08	13	1.3E+08	6	4.6E+07					5.5E+07
Peridinium sp.*	2.9E+04	506	9.5E+08	457	8.9E+08	48	7.5E+07	7	1.5E+07	77	1.3E+08	3.3E+08
Euglenophyceae												
Lepocinclis sp.*	7.2E+03	1	8.8E+05									7.3E+04
Phacus sp.*	4.6E+04					1	4.3E+06					1.5E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D16. Phytoplankton counts and biovolume, Site A (8/3/2011)

date 8/3/2011 Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										
Cocconeis sp.*	2.22E+03	3	7.23E+05	7	2.00E+06	7	2.07E+06	2	6.02E+05	1.35E+06
Fragilaria sp.*	2.03E+03	1	2.20E+05							2.06E+04
Nitzschia sp.*	3.57E+03	63	2.44E+07	55		25	1.18E+07	4	1.93E+06	7.21E+06
Chlorophyceae										
Closterium sp.*	7.48E+02			10	9.63E+05	12	1.19E+06			5.73E+05
Coelastrum sp.*	9.53E+03	1	1.03E+06	1	1.23E+06	3	3.80E+06			1.63E+06
Pediastrum sp. *	3.75E+03	5	2.03E+06	7	3.38E+06	5	2.49E+06			1.60E+06
Scenedesmus sp.*	3.11E+02			4	1.60E+05			4	1.68E+05	9.20E+04
Staurastrum sp.*	6.77E+03			1	8.72E+05					1.39E+05
Pandorina sp.**	7.80E+02					5	5.18E+05			1.82E+05
Ankyra sp.*	1.32E+02	1	1.44E+04							1.34E+03
Cryptophyceae										
Cryptomonas sp.*	2.28E+03	2500	2.15E+08	3300	6.30E+08	151	2.44E+06			1.21E+08
Cyanophyceae										
Anabaena sp.***	3.02E+05	37	1.12E+09	30	1.16E+09	9	4.75E+08	3	5.70E+06	4.60E+08
Aphanizomenon sp.***	3.60E+03	2100	8.20E+08	3500	1.62E+09	250	1.20E+08	38	1.85E+07	3.85E+08
Microcystis sp.**	2.70E+05	6	1.76E+08	6	2.09E+08	4	1.43E+08	3	1.10E+08	1.43E+08
Oscillatoria sp.***	7.61E+05	1	1.64E+08			1	1.65E+06			1.59E+07
Gomphosphaeria sp.*	2.07E+04	10	1.94E+07	10	2.31E+07	2	4.76E+06	2	7.15E+06	1.00E+07
Dinophyceae										
Ceratium sp.*	1.15E+05	31	3.86E+08	27	3.99E+08	6	9.14E+07			1.32E+08
Peridinium sp.*	2.62E+04	5559	6.27E+09	5162	6.93E+09	156	2.40E+08	35	4.91E+07	1.79E+09
Euglenophyceae										
Lepocinclis sp.*	1.12E+04			5	7.19E+06			8	1.21E+07	5.93E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D17. Phytoplankton counts and biovolume, Site A (8/17/2011)

date 8/17/2011 Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										
Aulacoseira sp.*	1.49E+03	153	2.29E+06	34	7.38E+06	14	1.96E+06	36	3.45E+06	3.21E+06
Cocconeis sp.*	2.30E+03	6	1.42E+06			7	1.51E+06	2	4.27E+05	8.23E+05
Synedra sp.*	1.69E+04			1	1.97E+06					3.03E+05
Nitzschia sp.*	2.30E+03							12	2.56E+06	1.05E+06
Chlorophyceae										
Closterium sp.*	8.17E+02	13	1.13E+06	8	7.94E+05	25	2.00E+06	8	6.31E+05	1.15E+06
Coelastrum sp.*	1.25E+03	32	4.10E+06	27	3.93E+06	19	2.23E+06	19	2.20E+06	2.68E+06
Characium sp.*	6.69E+02			1	7.79E+04					1.20E+04
Pediastrum sp. *	1.66E+04	17	4.25E+07	9	2.56E+07	11	1.31E+07	3	3.54E+06	1.43E+07
Scenedesmus sp.*	1.37E+02	4	5.60E+04	8	1.27E+05	30	3.84E+05	28	3.54E+05	2.96E+05
Staurastrum sp.*	6.77E+03			1	7.89E+05					1.21E+05
Quadrigula sp.*	2.75E+02					2	5.15E+04			1.67E+04
Pandorina sp.**	2.02E+03	6	1.24E+06			5	9.47E+05	4	7.49E+05	7.53E+05
Ankyra sp.*	1.01E+02	6	6.18E+04			2	1.88E+04			1.30E+04
Eudorina*	7.89E+03	1	8.08E+05					2	1.46E+06	6.90E+05
Cryptophyceae										
Cryptomonas sp.*	1.52E+03	4600	7.92E+08	4900	1.23E+09	5956	9.09E+08	2350	3.80E+08	7.28E+08
Chrysophyceae										
Dinobryon sp.*	3.31E+02			1	3.85E+04					5.91E+03
Cyanophyceae										
Anabaena sp.***	2.22E+05	46	2.82E+08	40	4.42E+08	7	6.62E+07	9	4.37E+07	1.38E+08
Aphanizomenon sp.***	2.21E+03	550	1.24E+08	720	1.85E+08	800	1.65E+08	300	6.12E+07	1.21E+08
Microcystis sp.**	1.93E+05			2	4.48E+07	2	3.61E+07			1.86E+07
Lyngbya sp.***	2.16E+04	12	2.65E+07	32	8.04E+07	16	3.23E+07	7	1.40E+07	3.15E+07
Dinophyceae	#DIV/0!									
Ceratium sp.*	6.80E+04	13	1.06E+08	15	1.39E+08	3	1.75E+07	10	5.76E+07	6.24E+07
Peridinium sp.*	2.73E+04	4375	5.76E+09	3965	5.91E+09	2805	3.27E+08	1921	2.31E+09	2.60E+09
Gymnodinium sp.*	1.97E+03	6	1.21E+06							1.34E+05
Euglenophyceae										
Lepocinclis sp.*	6.90E+03	2	3.53E+07			5	9.69E+07	16	3.51E+08	1.80E+08

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D18. Phytoplankton counts and biovolume, Site A (8/30/2011)

date 8/30/2011 Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										
Aulacoseira sp.*	4.72E+03	160	7.90E+07	150	6.89E+07	57	2.99E+07	116	6.03E+07	5.39E+07
Cocconeis sp.*	2.66E+03	6	1.67E+06	6	1.55E+06			2	5.86E+05	7.09E+05
Unkn. diatom	1.00E+04	1	1.05E+06							1.13E+05
Chlorophyceae										
Closterium sp.*	6.11E+04	14	1.60E+06	15	1.60E+06	16	2.20E+07	6	7.24E+05	8.15E+06
Coelastrum sp.*	1.25E+03	20	2.62E+06	16	1.95E+06	7	9.75E+05	6	8.28E+05	1.31E+06
Characium sp.*	6.69E+02	5	3.50E+05							3.78E+04
Oocystis sp.*	6.94E+02	20	1.45E+06							1.56E+05
Pediastrum sp. *	1.27E+04	7	9.33E+06	8	9.92E+06	8	1.13E+07	1	1.40E+06	7.37E+06
Scenedesmus sp.*	1.97E+02	16	3.30E+05	8	1.53E+05	4	8.77E+04	8	1.74E+05	1.57E+05
Elakatothrix sp.*	3.98E+02	2	8.33E+04							8.97E+03
Actiniastrum sp.*	7.22E+01			1	7.03E+03					1.47E+03
Pandorina sp.**	5.17E+02	53	2.87E+06	65	3.27E+06	10	5.76E+05	4	2.28E+05	1.27E+06
Ankyra sp.*	8.85E+01							1	9.75E+03	3.39E+03
Eudorina*	7.89E+03	15	1.24E+07							1.34E+06
Cryptophyceae										
Cryptomonas sp.*	2.35E+03	2100	7.55E+08	2000	6.73E+08	1200	4.69E+08	200	7.44E+07	4.06E+08
Chrysophyceae										
Dinobryon sp.*	3.91E+02	25	1.02E+06	35	1.33E+06	9	3.91E+05			5.20E+05
Cyanophyceae										
Anabaena sp.***	9.53E+04	46	6.25E+08	38	4.67E+08	11	1.45E+08	1	2.68E+07	2.23E+08
Aphanizomenon sp.***	6.39E+03	400	2.68E+08	1000	6.23E+08	600	4.27E+08	50	3.52E+07	3.15E+08
Microcystis sp.**	1.71E+05	1	1.79E+07							1.93E+06
Oscillatoria sp.***	1.23E+04	1	1.29E+06			1	1.37E+06	4	5.42E+06	2.48E+06
Lyngbya sp.***	2.93E+03	20	6.14E+06	2	5.71E+05					7.81E+05
Gomphosphaeria sp.*	7.12E+04	7	5.21E+07	20	1.39E+08	9	7.13E+07	1	7.85E+06	6.13E+07
Dinophyceae										
Ceratium sp.*	6.49E+04	4	2.72E+07	3	1.90E+07	1	7.23E+06			9.33E+06
Peridinium sp.*	2.70E+04	7705	9.65E+09	6700	7.80E+09	2500	3.33E+09	351	4.66E+08	3.95E+09
Gymnodinium sp.*	1.97E+03			1	1.92E+05					4.01E+04
Euglenophyceae										
Lepocinclis sp.*	2.01E+03							4	8.87E+05	3.08E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D19. Phytoplankton counts and biovolume, Site A (9/20/2011)

date 9/20/2011 Class/Genus	biovolume per unit μm^3	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	$\mu m^3/L$
Bacillariophyceae										
Aulacoseira sp.	2.03E+03	68	1.64E+07	10	1.99E+06	17	3.62E+06	25	6.14E+06	6.13E+06
Cocconeis sp.	3.01E+03	2	7.15E+05							1.18E+05
Navicula sp.	2.12E+03			5	1.04E+06					2.50E+05
Chlorophyceae										
Closterium sp.	9.88E+02	22	2.82E+06	25	2.68E+06	26	2.98E+06	42	4.40E+06	3.33E+06
Coelastrum sp.	1.25E+03	16	2.37E+06	14	1.71E+06	15	1.97E+06	19	2.87E+06	2.26E+06
Pediastrum sp.	3.38E+04	4	1.60E+07			8	2.48E+07			9.50E+06
Scenedesmus sp.	1.70E+02	4	8.04E+04			8	1.42E+05			5.25E+04
Ankyra sp.	1.01E+02			2	1.97E+04					4.75E+03
Cryptophyceae										
Cryptomonas sp.	2.18E+03	1700	8.72E+08	1600	7.15E+08	2750	1.44E+09	850	5.48E+08	8.89E+08
Chrysophyceae										
Dinobryon sp.	4.13E+02	35	1.72E+06	25	1.01E+06	29	1.26E+06	29	1.45E+06	1.33E+06
Cyanophyceae										
Anabaena sp.	5.76E+05	12	1.80E+09	4	6.58E+08	3	3.55E+08	2	4.06E+08	6.82E+08
Aphanizomenon sp.	2.01E+03	2700	6.44E+08	4050	7.96E+08	4200	8.84E+08	1850	4.49E+08	6.85E+08
Gomphosphaeria sp.	3.62E+04	1	4.29E+06					2	8.72E+06	3.48E+06
Dinophyceae										
Ceratium sp.	5.13E+04	11	6.69E+07			7	3.76E+07	2	1.24E+07	2.53E+07
Peridinium sp.	2.81E+04	456	7.85E+08	450	6.23E+08	440	6.52E+08	455	7.77E+08	7.07E+08
Euglenophyceae										
Euglena sp.	6.91E+02	1	8.20E+04							1.35E+04

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D20. Phytoplankton counts and biovolume, Site A (4/10/2011)

date 4/10/2011 Class/Genus	biovolume per unit μm^3	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	$\mu m^3/L$
Bacillariophyceae								
Cocconeis sp.*	4.36E+03	4	2.06E+06	1	4.98E+05			6.75E+05
Cymbella sp.*	9.01E+03	1	1.06E+06					2.50E+05
Navicula sp.*	2.11E+03	1	2.49E+05	1	2.42E+05			1.51E+05
Stephanodiscus sp.*	2.11E+04	1	2.49E+06					5.85E+05
Chlorophyceae								
Closterium sp.*	1.09E+03	36	4.65E+06	50	6.26E+06	64	7.94E+06	6.52E+06
Coelastrum sp.*	7.03E+03	8	6.64E+06	1	8.04E+05	1	7.97E+05	2.17E+06
Oocystis sp.*	7.98E+03	15	1.41E+07					3.32E+06
Pediastrum sp. *	5.13E+04			1	5.87E+06			2.25E+06
Staurastrum sp.*	6.77E+03	1	7.99E+05					1.88E+05
Quadrigula sp.*	3.98E+02	3	1.41E+05					3.31E+04
Ankyra sp.*	2.20E+02	6	1.56E+05	2	5.04E+04			5.61E+04
Eudorina sp.*	7.89E+03	31	2.65E+07	29	1.30E+07	29	2.59E+07	2.67E+07
Cryptophyceae								
Cryptomonas sp.*	2.82E+03	450	1.88E+08	500	2.35E+08	301	1.40E+08	1.88E+08
Cyanophyceae								
Aphanizomenon sp.***	7.21E+03	20	1.70E+07	9	7.43E+06	3	2.45E+06	7.79E+06
Gomphosphaeria sp.*	3.51E+04	5	2.07E+07					4.87E+06
Dinophyceae								
Peridinium sp.*	1.42E+04	3	5.01E+06	1	1.62E+06	2	3.21E+06	3.02E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D21. Phytoplankton counts and biovolume, Site A (10/18/2011)

date 10/18/2011 Class/Genus	biovolume per unit μm^3	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	μm^3/L	units/ml	μm^3/L	units/ml	μm^3/L	μm^3/L
Bacillariophyceae								
Cocconeis sp.*	4.93E+03	6	1.24E+07	8	1.58E+01			1569029
Cymbella sp.*	9.01E+03	2	1.06E+06					664762.3
Fragilaria sp.*	2.03E+03	120	1.02E+08	126	3.18E+07	80	1.66E+07	19036033
Navicula sp.*	3.15E+03	3	3.97E+06					500977.4
Stephanodiscus sp.*	2.11E+04	3		3	4.13E+06	1	2.16E+06	793912.4
Synedra sp.*	1.56E+04	6	2.13E+07	7	8.94E+06	7	1.02E+07	5109669
Nitzschia sp.*	2.30E+03	5	5.81E+06	1	2.84E+06			1091572
Cyclotella sp.*	8.56E+02		1.80E+06	13	1.51E+05			245955.4
Chlorophyceae								
Closterium sp.*	1.09E+03	16	7.36E+06	12	2.14E+06	10	1.12E+06	1340808
Coelastrum sp.*	1.15E+04	8	3.51E+07	16	4.90E+06	2	2.56E+06	5375972
Pediastrum sp. *	1.72E+04	1	7.23E+06	7	6.74E+06	2	3.53E+06	2208811
Scenedesmus sp.*	1.70E+02	4	2.85E+05					35977.76
Staurastrum sp.*	6.77E+03	1	2.85E+06					359258.6
Quadrigula sp.*	2.75E+02	17	1.96E+06	9	6.46E+05	12	3.38E+05	372064.9
Ankyra sp.*	2.20E+02	5	4.63E+05	10	4.32E+04	1	2.26E+04	66753.39
Eudorina*	7.89E+03	1	3.31E+06					418525.3
Cryptophyceae								
Cryptomonas sp.*	1.89E+03	3800	6.08E+09	3350	2.35E+09	2900	1.22E+09	1.22E+09
Cyanophyceae								
Anabaena sp.***	1.68E+06	1	7.06E+08					8.92E+07
Aphanizomenon sp.***	7.21E+03	250	7.57E+08	300	4.24E+06	3	2.22E+06	9.64E+07
Lyngbya sp.***	2.16E+04	1	9.06E+06					1.14E+06
Gomphosphaeria sp.*	3.51E+04	2	2.95E+07	3	9.51E+06			3.73E+06
Euglenophyceae								
Lepocinclis sp.*	5.82E+03	1	2.44E+06					3.08E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D22. Phytoplankton counts and biovolume, Site A (8/11/2011)

date 8/11/2011 Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										
Asterionella sp.*	1.13E+03	32	3.24E+06	82	8.24E+06	98	1.12E+07	34	3.52E+06	6.50E+06
Cocconeis sp.*	3.24E+03	2	5.82E+05	1	2.89E+05			2	5.95E+05	3.74E+05
Cymbella sp.*	9.01E+03							2	1.66E+06	5.36E+05
Fragilaria sp.*	2.03E+03	100	1.82E+07	78	1.41E+07	100	2.07E+07	70	1.31E+07	1.61E+07
Navicula sp.*	1.81E+03	2	3.26E+05	2	3.24E+05			1	1.67E+05	1.97E+05
Stephanodiscus sp.*	2.11E+04	18	3.41E+07	6	1.13E+07	4	8.59E+06	16	3.10E+07	2.12E+07
Synedra sp.*	1.42E+04	16	2.04E+07	12	1.52E+07	2	2.89E+06	18	2.35E+07	1.60E+07
Nitzschia sp.*	1.10E+04							8	8.16E+06	2.67E+06
Cyclotella sp.*	8.56E+02	2	1.54E+05							2.83E+04
Chlorophyceae										
Closterium sp.*	1.09E+03	2	1.97E+05	1	9.77E+04			1	1.01E+05	9.39E+04
Coelastrum sp.*	1.25E+04	1	1.12E+06					1	1.15E+06	5.79E+05
Characium sp.*	1.23E+03							2	2.26E+05	7.30E+04
Staurastrum sp.*	6.77E+03					1	6.90E+05			1.62E+05
Quadrigulla sp.*	2.75E+02	2	4.94E+04					2	5.06E+04	2.54E+04
Ankyra sp.*	2.20E+02	12	2.38E+05	8	1.57E+05			15	3.04E+05	1.83E+05
Cryptophyceae										
Cryptomonas sp.*	3.07E+03	14700	5.33E+09	19500	7.78E+09	17050	7.95E+09	17750	6.26E+09	6.88E+09
Chrysophyceae										
Anabaena sp.***	1.89E+04			1	1.68E+06	1	1.92E+06			8.86E+05
Aphanizomenon sp.***	7.21E+03	50	3.24E+07	50	3.22E+07	42	3.08E+07	45	2.98E+07	3.12E+07
Oscillatoria sp.***	1.53E+04			2	2.73E+06					7.02E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

D7.3. Phytoplankton abundance and biovolume, Site B (2010)

Table D23. Phytoplankton counts and biovolume, Site B (6/4/2010)

Class/Genus	biovolume per unit μm^3	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	$\mu m^3/L$
Bacillariophyceae								
Asterionella sp. *	1.01E+03			65	4.93E+06	55	4.40E+06	3.64E+06
Aulacoseira sp.*	1.36E+03	1	2.45E+04			45	4.87E+06	2.50E+06
Fragilaria sp.*	1.88E+03	1100	1.45E+08	960	1.36E+08	1280	1.90E+08	1.66E+08
Stephanodiscus sp.*	2.01E+04			35	5.30E+07	26	4.15E+07	3.62E+07
Unkn. diatom*	8.56E+02	1	6.01E+04					1.24E+04
Chlorophyceae								
Coelastrum sp.*	1.25E+04	15	1.32E+07			7	6.95E+06	6.28E+06
Pediastrum sp.*	5.13E+04			2	7.72E+06	1	4.07E+06	4.26E+06
Quadrigulla sp.*	2.75E+02	2	3.86E+04					7.96E+03
Elakatothrix sp.*	3.98E+02	6	1.67E+05	2	5.99E+04			5.13E+04
Eudorina sp.*	9.09E+02					15	1.08E+06	5.55E+05
Cryptophyceae								
Cryptomonas sp.	2.37E+03	4320	1.28E+08	4560	1.49E+08	5640	1.47E+08	1.43E+08
Cyanophyceae								
Anabaena sp.*	1.71E+04	1	3.76E+07	1	4.03E+07	4	1.70E+08	1.06E+08
Dinophyceae								
Ceratium sp.*	8.31E+04	1	1.29E+04	2	1.95E+06	1	1.03E+06	1.08E+06
Peridinium sp.*	1.29E+04					2	6.66E+06	3.42E+06
Synurophyceae								
Mallomonas sp.*	1.61E+03	1	8.04E+03			1	1.28E+05	6.71E+04

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D24. Phytoplankton counts and biovolume, Site B (6/18/2010)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Asterionella sp. *	1.01E+03	65	5.31E+06	28	2.20E+06	18	1.96E+06	2.27E+06
Aulacoseira sp.*	1.36E+03	11600	1.28E+09	23360	2.48E+09	13280	1.95E+09	1.94E+09
Cocconeis sp.*	4.93E+03					1	5.32E+05	4.38E+05
Fragilaria sp.*	1.88E+03	48880	7.44E+09	64760	9.48E+09	37360	7.56E+09	7.72E+09
Navicula sp.*	9.97E+02			7	5.44E+05			4.80E+04
Stephanodiscus sp.*	2.01E+04	15	2.45E+07	10	1.57E+07	8	1.74E+07	1.78E+07
Chlorophyceae								
Closterium sp.*	9.61E+04					7	2.13E+07	1.76E+07
Characium sp.*	1.23E+03			1	9.57E+04	1	1.32E+05	1.17E+05
Pediastrum sp.*	5.13E+04	9	3.74E+07	3	1.20E+07	1	5.53E+06	8.92E+06
Staurastrum sp.*	6.77E+03	5	2.75E+06					2.42E+05
Quadrigulla sp.*	2.75E+02	1	2.23E+04	2	4.29E+04	1	2.97E+04	3.02E+04
Eudorina sp.*	9.09E+02	3	2.21E+05	6	4.25E+05	9	8.83E+05	7.84E+05
Cryptophyceae								
Cryptomonas sp.*	1.61E+03	6560	1.66E+08	9480	2.50E+09	6320	2.75E+09	2.50E+09
Chrysophyceae								
Dinobryon sp.*	3.97E+02	50		38	1.18E+06	15	6.42E+05	6.32E+05
Cyanophyceae								
Anabaena sp.***	2.76E+05	44	1.91E+09	35	4.66E+07	34	6.26E+07	2.24E+08
Microcystis sp.**	1.80E+05	1	1.75E+06					1.54E+05
Dinophyceae								
Ceratium sp.*	8.31E+04	5	5.25E+06	3	1.94E+07	1	8.97E+06	9.56E+06
Peridinium sp.*	1.29E+04	6	2.04E+07	1	1.01E+06	10	1.39E+07	1.34E+07
Euglenophyceae								
Phacus sp.*	4.62E+04			1	3.61E+06			3.18E+05
Synurophyceae								
Mallomonas sp.*	1.61E+03	4	5.22E+05	2	2.51E+05	15	2.60E+06	2.21E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D25. Phytoplankton counts and biovolume. Site B (7/9/2010)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Fragilaria sp.*	1.88E+03	2280	5.29E+08	2920	4.29E+08	2240	2.53E+08	3.18E+08
Stephanodiscus sp.*	2.01E+04	2	4.97E+06	4	6.30E+06	6	7.27E+06	6.81E+06
Chlorophyceae								
Closterium sp.	1.09E+03	3	4.06E+05	4	3.43E+05	4	2.64E+05	2.95E+05
Coelastrum sp.*	1.25E+04			1	9.79E+05	1	7.54E+05	6.94E+05
Characium sp.*	1.23E+03	1	1.52E+05	1	9.60E+04			3.57E+04
Pediastrum sp.*	5.13E+04	1	6.34E+06	1	4.01E+06	4	1.24E+07	1.02E+07
Quadrigulla sp.*	2.75E+02	2	6.80E+04	1	2.15E+04			1.24E+04
Eudorina sp.*	9.09E+02	4	4.50E+05	1	7.11E+04			7.01E+04
Cryptophyceae								
Cryptomonas sp.*	1.61E+03	13440	5.72E+09	11720	3.36E+09	3080	7.69E+08	1.84E+09
Cyanophyceae								
Anabaena sp.***	1.86E+05	103	2.42E+08	99	1.12E+08	41	7.34E+07	1.02E+08
Gomphosphaeria sp.**	3.51E+04	33	1.43E+08	42	1.15E+08			3.78E+07
Dinophyceae								
Ceratium sp.*	8.31E+04	9	9.25E+07	2	1.30E+07	3	1.50E+07	2.47E+07
Peridinium sp.*	1.29E+04	19	3.04E+07	2920	2.95E+09	2200	1.71E+09	1.70E+09
Euglenophyceae								
Phacus sp.*	4.62E+04					40	1.11E+08	7.84E+07
Synurophyceae								
Mallomonas sp.*	1.61E+03	25	4.97E+06	30	3.77E+06	18	1.74E+06	2.50E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D26. Phytoplankton counts and biovolume, Site B (7/23/2010)

Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										
Aulacoseira sp.*	1.36E+03	17	2.58E+06	3	5.59E+05	15	2.31E+06	10	1.66E+06	2.89E+06
Cocconeis sp.*	4.93E+03			1	6.74E+05	1	5.56E+05			2.99E+05
Fragilaria sp.*	1.88E+03	400	8.37E+07	1440	3.69E+08	480	1.02E+08	1000	2.28E+08	3.40E+08
Navicula sp.*	9.97E+02					1	1.12E+05			3.59E+04
Stephanodiscus sp.*	2.01E+04	18	4.04E+07	9	2.47E+07	15	3.40E+07	11	2.69E+07	4.85E+07
Synedra sp.*	1.42E+04			1	1.94E+06					3.51E+05
Unkn. Diatom.*	8.56E+02	1	9.55E+04							1.48E+04
Chlorophyceae										
Closterium sp.*	1.07E+03	12	1.45E+06	11	1.61E+06	9	1.08E+06	6	7.80E+05	1.64E+06
Coelastrum sp.*	1.25E+04	1	1.40E+06			1	1.41E+06	1	1.52E+06	2.19E+06
Characium sp.*	1.23E+03	1	1.37E+05	1	1.68E+05	3	4.15E+05	2	2.98E+05	4.82E+05
Oocystis sp.*	1.59E+03			1	2.17E+05					3.93E+04
Pediastrum sp.*	5.13E+04	2	1.14E+07	1	7.01E+06	2	1.16E+07			6.73E+06
Staurastrum sp.*	6.77E+03			4	3.70E+06					6.70E+05
Cryptophyceae										
Cryptomonas sp.*	1.61E+03	3160	7.35E+08	1640	3.76E+08	2440	5.08E+08	1040	3.83E+08	7.28E+08
Cyanophyceae										
Anabaena sp.***	2.76E+05	8	7.30E+07	8	8.95E+07	4	6.61E+07	3	1.95E+08	2.44E+08
Aphanizomenon sp.***	7.21E+03	280	2.25E+08	600	5.92E+08	560	4.56E+08	480	4.21E+08	7.08E+08
Microcystis sp.**	1.80E+05	1	2.01E+07	3	7.39E+07	5	1.02E+08	4	8.76E+07	1.36E+08
Lyngbya sp.***	2.16E+04	10	2.41E+07	6	1.77E+07	2	4.87E+06	12	3.14E+07	3.99E+07
Gomphosphaeria sp.**	3.51E+04	5	1.96E+07	1	4.80E+06	2	7.93E+06	3	1.28E+07	1.92E+07
Dinophyceae										
Ceratium sp.*	8.31E+04	12	1.11E+08	15	1.70E+08	17	1.59E+08	5	5.05E+07	1.49E+08
Peridinium sp.*	2.74E+04	9962	1.44E+10	7365	1.30E+10	10243	1.49E+10	5800	9.11E+09	1.85E+10
Euglenophyceae										
Lepocinclis sp.*	1.12E+04					1	1.26E+06			4.02E+05
Synurophyeceae										
Mallomonas sp.*	1.61E+03					1	1.81E+05			5.78E+04

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D27. Phytoplankton counts and biovolume, Site B (8/6/2010)

Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										
Asterionella sp. *	1.01E+03									4.43E+05
Aulacoseira sp.*	1.36E+03					11	1.53E+06	1	1.49E+05	1.36E+05
Cocconeis sp.*	4.93E+03					1	5.02E+05			7.40E+06
Fragilaria sp.*	1.88E+03	35	8.14E+06	50	1.22E+07	24	4.59E+06	15	3.07E+06	1.47E+07
Stephanodiscus sp.*	2.01E+04	8	2.00E+07	6	1.57E+07	5	1.02E+07	6	1.31E+07	
Chlorophyceae										1.22E+06
Closterium sp.	1.07E+03	9	1.22E+06	9	1.28E+06	13	1.45E+06	8	9.49E+05	1.25E+06
Coelastrum sp.*	1.25E+04					4	5.10E+06			1.61E+05
Characium sp.*	1.23E+03			1	1.60E+05	1	1.25E+05	3	4.01E+05	1.81E+05
Oocystis sp.*	1.59E+03	4	7.88E+05							5.99E+06
Pediastrum sp.*	5.13E+04	1	6.36E+06	1	6.67E+06	1	5.22E+06	1	5.59E+06	3.88E+04
Quadrigulla sp.*	2.75E+02	4	1.36E+05			1	2.80E+04			
Cryptophyceae										9.76E+08
Cryptomonas sp.*	1.61E+03	6000	1.16E+09	6840	1.32E+09	4680	7.16E+08	2080	5.98E+08	
Cyanophyceae										8.97E+07
Anabaena sp.***	2.76E+05	7	7.90E+07	2	1.39E+08	1	5.45E+07	40	7.43E+07	1.29E+08
Aphanizomenon sp.***	7.21E+03	40	3.58E+07	200	1.88E+08	320	2.35E+08			4.90E+07
Microcystis sp.**	1.80E+05			2	4.69E+07	7	1.28E+08			2.00E+07
Lyngbya sp.***	2.16E+04	10	2.67E+07	8	2.24E+07	8	1.76E+07	5	1.18E+07	7.62E+06
Gomphosphaeria sp.**	3.51E+04	3	1.31E+07	1	4.57E+06	1	3.58E+06	3	1.15E+07	
Dinophyceae										1.87E+08
Ceratium sp.*	8.31E+04	18	1.85E+08	19	2.05E+08	21	1.78E+08	19	1.72E+08	1.40E+10
Peridinium sp.*	2.74E+04	11607	1.86E+10	8928	1.50E+10	11726	1.55E+10	3725	5.26E+09	
Euglenophyceae										1.63E+06
Lepocinclis sp.*	1.12E+04			3	4.36E+06	1	1.14E+06			4.43E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D28. Phytoplankton counts and biovolume, Site B (8/20/2010)

Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										
Aulacoseira sp.*	1.36E+03	16	2.86E+06	41	5.83E+06	42	5.93E+06	44	5.61E+06	3.28E+07
Cocconeis sp.*	4.93E+03			3	1.54E+06					1.46E+06
Cymbella sp.*	9.01E+03			1	9.39E+05					8.92E+05
Fragilaria sp.*	1.88E+03	800	1.97E+08	400	7.82E+07	640	1.24E+08	1040	1.82E+08	8.98E+08
Navicula sp.*	9.97E+02			1	1.04E+05					9.87E+04
Stephanodiscus sp.*	2.01E+04	1	2.64E+06	12	2.52E+07	13	2.71E+07	15	2.82E+07	1.45E+08
Chlorophyceae										
Closterium sp.*	1.07E+03					9	1.02E+06	12	1.22E+06	7.14E+06
Characium sp.*	1.23E+03	2	3.22E+05	4	5.11E+05	3	3.81E+05	1	1.15E+05	1.84E+06
Oocystis sp.*	1.59E+03			1	1.66E+05	4	6.58E+05	1	1.48E+05	1.92E+06
Pediastrum sp.*	5.13E+04	3	2.02E+07			3	1.59E+07			5.22E+07
Scenedesmus sp.*	1.89E+02					3	5.88E+04	2	3.54E+04	2.04E+05
Quadrigulla sp.*	2.75E+02			6	1.72E+05	80	2.28E+06	5	1.28E+05	5.45E+06
Ankyra sp.*	1.01E+02			80	8.39E+05			40	3.76E+05	1.59E+06
Cryptophyceae										
Cryptomonas sp.*	1.61E+03	13360	1.99E+09	14280	8.48E+08	9440	7.11E+08	4560	2.81E+08	4.65E+09
Cyanophyceae										
Anabaena sp.***	1.86E+05	12	2.89E+08	162	1.78E+08	124	9.67E+07	121	8.25E+07	8.00E+08
Microcystis sp.**	1.80E+05	3	7.10E+07	2	3.76E+07	2	3.73E+07	1	1.68E+07	2.14E+08
Lyngbya sp.***	2.16E+04	15	4.25E+07	8	1.80E+07	4	8.94E+06	5	1.01E+07	9.40E+07
Dinophyceae										
Ceratium sp.*	8.31E+04	28	3.06E+08	48	4.16E+08	920	7.92E+09	17	1.32E+08	1.84E+10
Peridinium sp.*	2.74E+04	6205	1.06E+10	5644	7.62E+09	5241	7.02E+09	3922	4.75E+09	4.16E+10
Euglenophyceae										
Lepocinclis sp.*	1.12E+04							1	1.04E+06	2.19E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D29. Phytoplankton counts and biovolume, Site B (9/3/2010)

Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										
Aulacoseira sp.*	1.36E+03			10	1.80E+06	8	1.16E+06	7	1.02E+06	1.04E+06
Cocconeis sp.*	4.93E+03			1	6.51E+05					1.26E+05
Cymbella sp.*	9.01E+03							1	9.62E+05	2.95E+05
Fragilaria sp.*	1.88E+03	3240	5.15E+08	880	2.18E+08	2200	4.37E+08	640	1.28E+08	3.14E+08
Stephanodiscus sp.*	2.01E+04	25	4.26E+07	35	9.30E+07	120	2.56E+08	10	2.15E+07	1.16E+08
Chlorophyceae										
Closterium sp.*	1.07E+03	36	3.33E+06	35	5.06E+06	25	2.90E+06	10	1.17E+06	2.86E+06
Coelastrum sp.*	1.25E+04	6	6.36E+06					1	1.34E+06	1.51E+06
Characium sp.*	1.23E+03	1	1.04E+05	1	1.62E+05			2	2.62E+05	1.30E+05
Oocystis sp.*	1.59E+03	8	1.08E+06					8	1.36E+06	6.02E+05
Pediastrum sp.*	5.13E+04	4	1.74E+07	1	6.78E+06	1	5.44E+06			6.10E+06
Quadrigulla sp.*	2.75E+02	20	4.66E+05	9	3.27E+05	14	4.08E+05	13	3.82E+05	3.94E+05
Ankyra sp.*	1.01E+02							2	2.15E+04	6.58E+03
Cryptophyceae										
Cryptomonas sp.*	1.61E+03	7280	1.60E+09	1960	8.54E+08	4400	1.34E+09	5600	1.38E+09	1.30E+09
Cyanophyceae										
Anabaena sp.***	2.76E+05	5	2.27E+08	3	1.44E+08	4	2.27E+08	6	3.43E+08	2.46E+08
Aphanizomenon sp.***	7.21E+03	360	2.20E+08	200	1.91E+08	360	2.75E+08	280	2.16E+08	2.31E+08
Microcystis sp.**	1.80E+05	5	7.63E+07	3	7.14E+07	7	1.34E+08	2	3.85E+07	8.25E+07
Dinophyceae										
Ceratium sp.*	8.31E+04	310	2.18E+09	345	3.79E+09	320	2.82E+09	280	2.48E+09	2.79E+09
Peridinium sp.*	2.74E+04			6212	1.07E+10	9850	1.35E+10	9365	1.29E+10	1.23E+10
Synurophyceae										
Mallomonas sp.*	1.61E+03			2	4.25E+05			5	8.58E+05	3.45E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D30. Phytoplankton counts and biovolume, Site B (9/17/2010)

Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										
Aulacoseira sp.*	1.36E+03	12	1.67E+06	9	9.65E+05	4	5.94E+05	7	1.12E+06	1.00E+06
Cocconeis sp.*	4.93E+03	2	1.01E+06							1.62E+05
Cymbella sp.*	9.01E+03			1	7.09E+05					1.33E+05
Fragilaria sp.*	1.88E+03	2360	4.51E+08	1280	1.89E+08	2520	5.15E+08	1600	3.53E+08	3.93E+08
Navicula sp.*	9.97E+02			2	1.57E+05					2.94E+04
Stephanodiscus sp.*	2.01E+04	16	3.28E+07	10	1.58E+07	8	1.75E+07	7	1.66E+07	1.94E+07
Chlorophyceae										
Closterium sp.	1.07E+03	39	4.33E+06	20	1.72E+06	15	1.79E+06	9	1.14E+06	1.98E+06
Coelastrum sp.*	1.25E+04	3	3.83E+06	3	2.95E+06			2	2.94E+06	2.09E+06
Characium sp.*	1.23E+03			1	9.65E+04	1	1.34E+05			6.34E+04
Oocystis sp.*	1.59E+03	10	1.62E+06	10	1.25E+06			2	3.74E+05	6.11E+05
Pediastrum sp.*	5.13E+04			1	4.03E+06	1	5.59E+06			2.65E+06
Staurastrum sp.*	6.77E+03	2	1.38E+06	4	2.13E+06			4	3.19E+06	1.62E+06
Quadrigulla sp.*	2.75E+02	3	8.41E+04	4	8.65E+04	5	1.50E+05	7	2.26E+05	1.51E+05
Ankyra sp.*	1.01E+02	320	3.28E+06	8	6.33E+04					5.39E+05
Elakatothrix sp.*	3.98E+02	6	2.43E+05							3.91E+04
Cryptophyceae										
Cryptomonas sp.*	4.83E+03	8560	2.08E+09	5960	8.45E+08	4960	1.58E+09	2640	1.18E+09	1.40E+09
Cyanophyceae										
Anabaena sp.***	2.76E+05	11	3.36E+08	4	1.68E+08	5	9.29E+06	8	5.04E+08	2.46E+08
Aphanizomenon sp.***	7.21E+03					3	2.36E+06	3	2.55E+06	1.60E+06
Microcystis sp.**	1.80E+05	2	3.68E+07	2	2.84E+07	1	1.96E+07			1.79E+07
Lyngbya sp.***	2.16E+04	1	2.20E+06	1	1.70E+06	1	2.35E+06	15	3.81E+07	1.34E+07
Gomphosphaeria sp.**	3.51E+04	1	3.58E+06	1	2.76E+06					1.09E+06
Dinophyceae										
Ceratium sp.*	8.31E+04	16	1.36E+08	7	4.58E+07	5	4.53E+07	7	6.84E+07	6.71E+07
Peridinium sp.*	2.74E+04	9255	1.22E+10	10250	1.04E+10	12520	1.76E+10	4560	6.94E+09	1.21E+10
Gymnodinium sp. *	1.97E+03			2	3.09E+05					5.80E+04
Euglenophyceae										
Lepocinclis sp.*	1.12E+04	3	3.42E+06	2	1.76E+06					8.79E+05
Synurophyceae										
Mallomonas sp.*	1.61E+03	280	4.59E+07	120	1.52E+07	1	1.75E+05			1.03E+07

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D31. Phytoplankton counts and biovolume, Site B (10/1//2010)

Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										1.23E+05
Cocconeis sp.*	4.93E+03			1	4.69E+05					1.02E+09
Fragilaria sp.*	1.88E+03	3840	7.19E+08	6120	1.09E+09	6080	1.02E+09	5280	1.15E+09	2.63E+04
Navicula sp.*	9.97E+02					1	8.96E+04			2.72E+07
Stephanodiscus sp.*	2.01E+04	15	3.01E+07	12	2.30E+07	10	1.81E+07	17	3.97E+07	3.54E+05
Synedra sp.*	1.42E+04			1	1.35E+06					
Chlorophyceae										4.84E+06
Closterium sp.*	6.44E+04	13	2.04E+07	19	1.98E+06	14	1.38E+06	6	7.63E+05	1.79E+06
Coelastrum sp.*	1.25E+04	1	1.25E+06	5	5.95E+06					2.23E+04
Characium sp.*	1.23E+03	1	1.22E+05							5.39E+05
Oocystis sp.*	1.59E+03	6	9.51E+05	8	1.21E+06			1	1.84E+05	3.98E+06
Pediastrum sp.*	5.13E+04			1	4.88E+06	2	9.21E+06			6.90E+03
Scenedesmus sp.*	1.89E+02	2	3.78E+04							1.54E+06
Staurastrum sp.*	6.77E+03					4	2.43E+06	4	3.15E+06	3.70E+04
Quadrigulla sp.*	2.75E+02			1	2.62E+04	3	7.41E+04	1	3.19E+04	1.58E+05
Ankyra sp.*	1.01E+02	35	3.51E+05	25	2.39E+05	7	6.33E+04	4	4.67E+04	
Cryptophyceae										2.77E+09
Cryptomonas sp.*	1.61E+03	12240	2.77E+09	11560	3.67E+09	13800	4.44E+09	3800	8.23E+08	
Cyanophyceae										4.61E+07
Anabaena sp.***	2.76E+05			8	1.12E+08	1	4.81E+07			3.15E+06
Aphanizomenon sp.***	7.21E+03	6	4.32E+06	1	6.86E+05	8	5.18E+06	3	2.51E+06	9.20E+06
Lyngbya sp.***	2.16E+04	2	4.31E+06	5	1.03E+07	2	3.88E+06	7	1.75E+07	
Dinophyceae										1.80E+07
Ceratium sp.*	8.31E+04	5	4.15E+07	4	3.16E+07	1	7.47E+06			6.18E+07
Peridinium sp.*	2.74E+04	96	1.27E+08	65	8.00E+07	52	6.04E+07	35	5.26E+07	
Synurophyceae										2.43E+05
Mallomonas sp.*	1.61E+03			6	9.18E+05	1	8.04E+03			1.23E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D32. Phytoplankton counts and biovolume, Site B (10/1//010)

Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										1.23E+05
Cocconeis sp.*	4.93E+03			1	4.69E+05					1.02E+09
Fragilaria sp.*	1.88E+03	3840	7.19E+08	6120	1.09E+09	6080	1.02E+09	5280	1.15E+09	2.63E+04
Navicula sp.*	9.97E+02					1	8.96E+04			2.72E+07
Stephanodiscus sp.*	2.01E+04	15	3.01E+07	12	2.30E+07	10	1.81E+07	17	3.97E+07	3.54E+05
Synedra sp.*	1.42E+04			1	1.35E+06					
Chlorophyceae										4.84E+06
Closterium sp.*	6.44E+04	13	2.04E+07	19	1.98E+06	14	1.38E+06	6	7.63E+05	1.79E+06
Coelastrum sp.*	1.25E+04	1	1.25E+06	5	5.95E+06					2.23E+04
Characium sp.*	1.23E+03	1	1.22E+05							5.39E+05
Oocystis sp.*	1.59E+03	6	9.51E+05	8	1.21E+06			1	1.84E+05	3.98E+06
Pediastrum sp.*	5.13E+04			1	4.88E+06	2	9.21E+06			6.90E+03
Scenedesmus sp.*	1.89E+02	2	3.78E+04							1.54E+06
Staurastrum sp.*	6.77E+03					4	2.43E+06	4	3.15E+06	3.70E+04
Quadrigulla sp.*	2.75E+02			1	2.62E+04	3	7.41E+04	1	3.19E+04	1.58E+05
Ankyra sp.*	1.01E+02	35	3.51E+05	25	2.39E+05	7	6.33E+04	4	4.67E+04	
Cryptophyceae										2.77E+09
Cryptomonas sp.*	1.61E+03	12240	2.77E+09	11560	3.67E+09	13800	4.44E+09	3800	8.23E+08	
Cyanophyceae										4.61E+07
Anabaena sp.***	2.76E+05			8	1.12E+08	1	4.81E+07			3.15E+06
Aphanizomenon sp.***	7.21E+03	6	4.32E+06	1	6.86E+05	8	5.18E+06	3	2.51E+06	9.20E+06
Lyngbya sp.***	2.16E+04	2	4.31E+06	5	1.03E+07	2	3.88E+06	7	1.75E+07	
Dinophyceae										1.80E+07
Ceratium sp.*	8.31E+04	5	4.15E+07	4	3.16E+07	1	7.47E+06			6.18E+07
Peridinium sp.*	2.74E+04	96	1.27E+08	65	8.00E+07	52	6.04E+07	35	5.26E+07	
Synurophyceae										2.43E+05
Mallomonas sp.*	1.61E+03			6	9.18E+05	1	8.04E+03			1.23E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D33. Phytoplankton counts and biovolume, Site B (10/15/2010)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Cocconeis sp.*	4.93E+03	6	1.24E+07	8	1.58E+01			1569029
Cymbella sp.*	9.01E+03	2	1.06E+06					664762.3
Fragilaria sp.*	2.03E+03	120	1.02E+08	126	3.18E+07	80	1.66E+07	19036033
Navicula sp.*	3.15E+03	3	3.97E+06					500977.4
Stephanodiscus sp.*	2.11E+04	3		3	4.13E+06	1	2.16E+06	793912.4
Synedra sp.*	1.56E+04	6	2.13E+07	7	8.94E+06	7	1.02E+07	5109669
Nitzschia sp.*	2.30E+03	5	5.81E+06	1	2.84E+06			1091572
Cyclotella sp.*	8.56E+02		1.80E+06	13	1.51E+05			245955.4
Chlorophyceae								
Closterium sp.*	1.09E+03	16	7.36E+06	12	2.14E+06	10	1.12E+06	1340808
Coelastrum sp.*	1.15E+04	8	3.51E+07	16	4.90E+06	2	2.56E+06	5375972
Pediastrum sp. *	1.72E+04	1	7.23E+06	7	6.74E+06	2	3.53E+06	2208811
Scenedesmus sp.*	1.70E+02	4	2.85E+05					35977.76
Staurastrum sp.*	6.77E+03	1	2.85E+06					359258.6
Quadrigula sp.*	2.75E+02	17	1.96E+06	9	6.46E+05	12	3.38E+05	372064.9
Ankyra sp.*	2.20E+02	5	4.63E+05	10	4.32E+04	1	2.26E+04	66753.39
Eudorina*	7.89E+03	1	3.31E+06					418525.3
Cryptophyceae								
Cryptomonas sp.*	1.89E+03	3800	6.08E+09	3350	2.35E+09	2900	1.22E+09	1.22E+09
Cyanophyceae								
Anabaena sp.***	1.68E+06	1	7.06E+08					8.92E+07
Aphanizomenon sp.***	7.21E+03	250	7.57E+08	300	4.24E+06	3	2.22E+06	9.64E+07
Lyngbya sp.***	2.16E+04	1	9.06E+06					1.14E+06
Gomphosphaeria sp.*	3.51E+04	2	2.95E+07	3	9.51E+06			3.73E+06
Euglenophyceae								
Lepocinclis sp.*	5.82E+03	1	2.44E+06					3.08E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

D7.4. Phytoplankton abundance and biovolume, Site B (2011)

Table D34. Phytoplankton counts and biovolume, Site B (6/30/2011)

Class/Genus	biovolume per unit μm^3	water depth				depth weighted average biovolume
		at the surface		at the 2 × Secchi depth		
		units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	$\mu m^3/L$
Bacillariophyceae						
Asterionella sp.*	1.22E+03	5450	7.76E+08	11100	1.48E+09	1.10E+09
Cocconeis sp.*	1.29E+04	3	4.52E+06	5	7.04E+06	5.68E+06
Fragilaria sp.*	1.88E+03	6700	1.46E+09	3950	8.06E+08	1.16E+09
Stephanodiscus sp.*	2.18E+04	16	4.06E+07	14	3.32E+07	3.72E+07
Chlorophyceae						0.00E+00
Closterium sp.*	1.55E+03	2	3.61E+05		0.00E+00	1.95E+05
Coelastrum sp. *	6.73E+03			4	2.93E+06	1.35E+06
Pediastrum sp.*	1.08E+04	3	3.78E+06	2	2.35E+06	3.12E+06
Staurastrum sp.*	6.77E+03	1	7.89E+05		0.00E+00	4.25E+05
Cryptophyceae						
Cryptomonas sp.*	1.76E+03	12350	1.00E+09	15150	8.10E+08	9.13E+08
Chrysophyceae						
Dinobryon sp.*	2.96E+02	1150	3.97E+07	1600	5.16E+07	4.52E+07
Cyanophyceae			0.00E+00		0.00E+00	0.00E+00
Anabaena sp.***	1.83E+03	7	1.49E+06	14	2.79E+06	2.09E+06
Aphanizomenon sp.***	3.32E+03	350	1.36E+08	62	2.24E+07	8.34E+07
Dinophyceae						
Ceratium sp.*	9.24E+04	15	1.61E+08			8.70E+07
Peridinium sp.*	3.37E+04	6	2.36E+07	25	8.91E+07	5.38E+07

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D35. Phytoplankton counts and biovolume, Site B (7/13/2011)

Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										
Asterionella sp.*	1.12E+03	8	9.43E+05					7	8.38E+05	4.46E+05
Cocconeis sp.*	9.24E+02	6	5.84E+05		0.00E+00	7	7.33E+05	2	1.98E+05	3.57E+05
Fragilaria sp.*	2.17E+03	1905	4.34E+08	100	2.16E+07	1400	3.43E+08	4450	1.03E+09	5.19E+08
Stephanodiscus sp.*	1.27E+04	5	6.68E+06	4	5.06E+06	2	2.88E+06	1	1.36E+06	3.51E+06
Chlorophyceae										
Closterium sp.*	9.86E+02	2	2.08E+05	2	1.96E+05	4	4.47E+05	1	1.05E+05	2.32E+05
Characium sp.*	1.36E+03	3	4.28E+05	2	2.70E+05	4	6.14E+05	2	2.90E+05	3.93E+05
Pediastrum sp.*	2.08E+04	4	8.76E+06	7	1.45E+07	3	7.06E+06	7	1.56E+07	1.20E+07
Staurastrum sp.*	4.84E+04	5	2.55E+07	2	9.64E+06	3	1.64E+07	3	1.55E+07	1.61E+07
Quadrigulla sp.*	2.75E+02					4	1.25E+05			3.23E+04
Cryptophyceae										
Cryptomonas sp.*	1.18E+03	3238	1.91E+08	3900	1.18E+08	2600	3.52E+07	3900	1.33E+08	1.14E+08
Chrysophyceae										
Dinobryon sp.*	5.94E+02	8	5.00E+05	1	4.73E+05	2	1.35E+05			2.29E+05
Cyanophyceae										
Anabaena sp.***	3.08E+06	52	2.68E+09	52	1.31E+09	27	1.44E+09	6	6.67E+08	1.36E+09
Aphanizomenon sp.***	2.75E+03	10100	2.92E+09	14850	4.06E+09	6910	2.15E+09	9650	2.83E+09	2.95E+09
Microcystis sp.**	7.35E+04					3	2.50E+07	1	7.86E+06	9.15E+06
Gomphosphaeria sp.*	1.53E+04	9	1.45E+07	12	1.83E+07	10	1.73E+07	9	1.47E+07	1.62E+07
Dinophyceae										0.00E+00
Ceratium sp.*	9.19E+04	1	9.68E+06	1	9.15E+06	2	2.08E+07	1	9.83E+06	1.25E+07
Peridinium sp.*	3.05E+04	53	1.17E+08	50	9.47E+07	33	7.63E+07	27	5.30E+07	7.96E+07

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D36. Phytoplankton counts and biovolume, Site B (7/20/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Cocconeis sp.*	6.70E+03	1	7.89E+05					2.88E+05
Fragilaria sp.*	1.50E+03	100	1.77E+07	286	4.92E+07	650	9.54E+07	5.41E+07
Stephanodiscus sp.*	7.76E+04					3	2.28E+07	8.11E+06
Synedra sp.*	1.25E+04	2	2.93E+06	1	1.43E+06			1.47E+06
Chlorophyceae								
Closterium sp.*	7.29E+03	1	9.54E+04	1	9.31E+04	1	1.35E+06	6.08E+04
Pediastrum sp.*	1.80E+04	6	1.27E+07	9	1.86E+07	5	8.79E+06	1.29E+07
Cryptophyceae								
Cryptomonas sp.*	1.03E+03	16400	2.87E+09	1238	3.74E+08	650	1.89E+08	1.22E+09
Cyanophyceae								
Anabaena sp.***	6.82E+05	32	4.64E+09	4	3.52E+06	3	1.34E+08	1.74E+09
Aphanizomenon sp.***	2.66E+03	68700	2.15E+10	12381	3.77E+09	4850	1.26E+09	9.35E+09
Microcystis sp. **	6.99E+04	3	2.47E+07			2	1.37E+07	1.39E+07
Gomphosphaeria sp.**	1.53E+04	1	1.80E+06					6.59E+05
Dinophyceae								
Ceratium sp.*	9.68E+04	20	2.28E+08	4	4.44E+07	1	9.47E+06	9.90E+07
Peridinium sp.*	1.36E+04	25	4.01E+07	30	4.69E+07	12	1.60E+07	

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D37. Phytoplankton counts and biovolume, Site B (7/27/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Aulacoseira sp.*	1.41E+03							
Cocconeis sp.*	5.56E+03			10	5.58E+06			1.81E+06
Fragilaria sp.*	1.19E+03	12	1.31E+06	79	9.39E+06			3.20E+06
Chlorophyceae								
Closterium sp.*	1.04E+03	3	2.88E+05	1	1.05E+05			6.86E+04
Coelastrum sp.*	1.22E+04			2	2.45E+06			7.93E+05
Pediastrum sp.*	1.27E+04	5	5.85E+06	8	1.02E+07	2	2.38E+06	5.33E+06
Scenedesmus sp.*	1.40E+02			4	5.61E+04			1.82E+04
Quadrigulla sp.*	2.75E+02			4	1.10E+05			3.57E+04
Pandorina sp.*	4.27E+03			8	3.42E+06			1.11E+06
Eudorina sp.*	2.41E+03			4	9.67E+05			3.14E+05
Cryptophyceae								
Cryptomonas sp.*	3.94E+03	650	########	1800	636109966			2.70E+08
Cyanophyceae								
Anabaena sp.***	6.46E+05	268	2.24E+09	10	1.93E+07	106	7.64E+08	7.00E+08
Aphanizomenon sp.***	1.98E+03	70150	1.28E+10	44750	8.89E+09	15750	2.92E+09	6.04E+09
Microcystis sp. **	1.75E+05			35	6.14E+08	1	1.64E+07	2.08E+08
Gomphosphaeria sp.**	1.79E+04	1	1.65E+06	2	3.60E+06			1.36E+06
Dinophyceae								
Ceratium sp.*	8.22E+04	12	9.08E+07	21	1.73E+08			6.71E+07
Peridinium sp.*	2.85E+04	8212	1.15E+10	6521	1.00E+10	300	4.24E+08	4.79E+09

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D38. Phytoplankton counts and biovolume, Site B (8/3/2011)

Class/Genus	biovolume per unit µm³	water depth								depthweighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										
Aulacoseira sp.*	1.04E+03	10	9.69E+05	34	3.29E+06					8.60E+05
Cocconeis sp.*	2.22E+03	7	1.46E+06	6	1.25E+06	5	1.04E+06	3	6.24E+05	9.91E+05
Fragilaria sp.*	2.03E+03			16	3.04E+06	18	3.42E+06	12	2.28E+06	2.44E+06
Synedra sp.*	1.42E+04					1	1.33E+06	1	1.33E+06	8.50E+05
Nitzschia sp.*	9.08E+02	900	7.64E+07	800	6.79E+07	950	8.07E+07	34	2.89E+06	4.87E+07
Chlorophyceae										
Closterium sp.*	7.48E+02	10	6.99E+05	10	6.99E+05	5	3.50E+05	8	5.60E+05	5.53E+05
Coelastrum sp.*	9.53E+03	14	1.25E+07			12	1.07E+07	1	8.92E+05	5.00E+06
Characium sp.*				1	1.27E+05	2	2.54E+05			9.69E+04
Pediastrum sp.*	3.75E+03	11	3.86E+06	15	5.26E+06	13	4.56E+06	6	2.10E+06	3.71E+06
Scenedesmus sp.*	3.11E+02	12	3.49E+05			7	2.03E+05			1.04E+05
Staurastrum sp.*	2.08E+04					1	1.95E+06			5.31E+05
Pandorina sp.*	2.02E+03	17	3.22E+06	26	4.92E+06	23	4.35E+06			2.72E+06
Ankyra sp.*	1.01E+02	1	9.41E+03			2	1.88E+04			6.45E+03
Eudorina sp.*	2.41E+03	4	9.02E+05	5	1.13E+06	8	1.80E+06	6	1.35E+06	1.36E+06
Cryptophyceae										
Cryptomonas sp.*	1.55E+03	5150	1.50E+09	4350	1.18E+09	4000	1.22E+09	1850	3.23E+08	9.21E+08
Chrysophyceae										
Dinobryon sp.*		2	1.11E+05							1.56E+04
Cyanophyceae										
Anabaena sp.***	3.02E+05	44	1.56E+09	66	9.47E+08	85	6.49E+08	19	4.55E+08	7.72E+08
Aphanizomenon sp.***	3.60E+03	3250	1.09E+09	4300	1.45E+09	5400	1.82E+09	1500	5.05E+08	1.15E+09
Microcystis sp. **	2.70E+05	23	5.81E+08	15	3.79E+08	24	6.06E+08	8	2.02E+08	4.04E+08
Oscillatoria sp.***				1	1.15E+06					2.52E+05
Lyngbya sp.***	1.79E+04	1	1.68E+06					2	3.35E+06	1.47E+06
Gomphosphaeria sp.**		1	1.68E+06	9	1.51E+07	21	3.52E+07	2	3.35E+06	1.44E+07
Dinophyceae										
Ceratium sp.*	1.15E+05	19	2.04E+08	27	2.90E+08	35	3.75E+08	28	3.00E+08	3.05E+08
Peridinium sp.*	2.73E+04	5605	8.05E+09	8350	1.47E+10	6550	1.23E+10	3100	5.38E+09	9.67E+09
Euglenophyceae										
Lepocinclis sp.	1.12E+04	3	3.14E+06	1	1.05E+06	7	7.32E+06	5	5.23E+06	4.58E+06
Synurophyceae										
Mallomonas sp.*	1.61E+03	50	7.52E+06	10	1.50E+06	7	1.05E+06			1.67E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D39. Phytoplankton counts and biovolume, Site B (8/17/2011)

Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										
Aulacoseira sp.*	1.49E+03	7	1.05E+06	24	4.06E+06	5	7.45E+05	400	6.14E+07	2.49E+07
Cocconeis sp.*	2.30E+03			2	5.22E+05	5	1.15E+06	26	6.16E+06	2.81E+06
Nitzschia sp.*	9.08E+02			2	2.06E+05			1	9.34E+04	7.42E+04
Chlorophyceae										
Closterium sp.*	8.53E+02	26	2.22E+06	33	3.12E+06	33	2.81E+06	26	2.24E+06	2.56E+06
Coelastrum sp.*	1.65E+04	20	3.30E+07	15	2.80E+07	10	1.64E+07	15	2.54E+07	2.45E+07
Characium sp.*	6.69E+02			1	7.59E+04					1.40E+04
Pediastrum sp.*	2.44E+04	7	1.71E+07	9	2.49E+07	8	1.95E+07	7	1.76E+07	1.94E+07
Scenedesmus sp.*	1.37E+02	400	5.49E+06	8	1.24E+05	8	1.09E+05	4	5.63E+04	8.85E+05
Actinastrum sp.*	9.41E+03			7	7.46E+06					1.38E+06
Pandorina sp.*	2.02E+03			2	4.58E+05	1	2.02E+05	50	1.04E+07	4.18E+06
Ankyra sp.*	1.01E+02	150	1.51E+06	200	2.28E+06					6.44E+05
Eudorina sp.*	7.89E+03							1	8.12E+05	3.15E+05
Cryptophyceae										
Cryptomonas sp.*	2.28E+03	5100	9.02E+08	5000	7.21E+08	3900	1.39E+09	3350	3.47E+08	7.89E+08
Cyanophyceae										
Anabaena sp.***	2.22E+05	153	9.06E+08	4	1.78E+08	150	7.85E+08	56	5.12E+08	5.85E+08
Aphanizomenon sp.***	2.21E+03	2700	5.97E+08	200	5.00E+07	1316	2.90E+08	200	4.54E+07	1.96E+08
Microcystis sp. **	1.93E+05			11	2.40E+08	4	7.69E+07	18	3.57E+08	2.04E+08
Oscillatoria sp.***				1	1.39E+06	1	1.23E+06	1	1.26E+06	1.09E+06
Lyngbya sp.***	2.16E+04	600	1.30E+09	1100	2.69E+09			400	8.88E+08	1.03E+09
Gomphosphaeria sp.**	3.88E+04	2	7.79E+06	41	1.80E+08	27	1.05E+08	3	1.20E+07	6.84E+07
Dinophyceae										
Ceratium sp.*	6.22E+04	8	4.99E+07	16	1.13E+08	12	7.45E+07	6	3.84E+07	6.39E+07
Peridinium sp.*	2.73E+04	5700	7.26E+09	3745	5.53E+09	4850	6.14E+09	1875	2.52E+09	4.79E+09
Euglenophyceae										
Euglena sp.	2.62E+03			3	8.90E+05			3	8.08E+05	4.77E+05
Lepocinclis sp.	6.90E+03	2	1.38E+06	2	1.56E+06			16	1.14E+07	4.90E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D40. Phytoplankton counts and biovolume, Site B (8/30/2011)

Class/Genus	biovolume per unit µm³	water depth								depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		at the 0.5m from the bottom		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae										
Aulacoseira sp.*	1.49E+03	7	1.05E+06	24	4.06E+06	5	7.45E+05	400	6.14E+07	2.51E+07
Cocconeis sp.*	2.30E+03			2	5.22E+05	5	1.15E+06	26	6.16E+06	2.82E+06
Nitzschia sp.*	9.08E+02			2	2.06E+05			1	9.34E+04	7.52E+04
Chlorophyceae										
Closterium sp.*	8.17E+02	26	2.22E+06	33	3.12E+06	33	2.81E+06	26	2.24E+06	2.56E+06
Coelastrum sp.*	1.65E+04	20	3.30E+07	15	2.80E+07	10	1.64E+07	15	2.54E+07	2.45E+07
Characium sp.*	6.69E+02			1	7.59E+04					1.43E+04
Pediastrum sp.*	2.44E+04	7	1.71E+07	9	2.49E+07	8	1.95E+07	7	1.76E+07	1.94E+07
Scenedesmus sp.*	1.37E+02	400	5.49E+06	8	1.24E+05	8	1.09E+05	4	5.63E+04	8.61E+05
Pandorina sp.*	2.02E+03			2	4.58E+05	1	2.02E+05	50	1.04E+07	4.20E+06
Ankyra sp.*	1.01E+02	150	1.51E+06	200	2.28E+06					6.46E+05
Eudorina sp.*	7.89E+03							1	8.12E+05	3.17E+05
Cryptophyceae	3.30E+03									
Cryptomonas sp.*	6.25E+02	8250	3.58E+08	8650	3.67E+08	4700	3.48E+08	6000	2.13E+08	3.01E+08
Cyanophyceae										
Anabaena sp.***	2.22E+05	153	9.06E+08	4	1.78E+08	150	7.85E+08	56	5.12E+08	5.81E+08
Aphanizomenon sp.***	2.21E+03	2700	5.97E+08	200	5.00E+07	1316	2.90E+08	200	4.54E+07	1.93E+08
Microcystis sp. **	1.93E+05			11	2.40E+08	4	7.69E+07	18	3.57E+08	2.06E+08
Oscillatoria sp.***				1		1		1		
Lyngbya sp.***	2.16E+04	600	1.30E+09	1100	2.69E+09			400	8.88E+08	1.04E+09
Gomphosphaeria sp.**	3.88E+04	2	7.79E+06	41	1.80E+08	27	1.05E+08	3	1.20E+07	6.89E+07
Dinophyceae										
Ceratium sp.*	6.22E+04	8	4.99E+07	16	1.13E+08	12	7.45E+07	6	3.84E+07	6.41E+07
Peridinium sp.*	2.73E+04	5700	7.26E+09	3745	5.53E+09	4850	6.14E+09	1875	2.52E+09	4.78E+09
Euglenophyceae	2.73E+04									
Euglena sp.*	2.62E+03			3	8.90E+05			3	8.08E+05	4.83E+05
Lepocinclis sp.*	6.90E+03	2	1.38E+06	2	1.56E+06			16	1.14E+07	4.92E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D41. Phytoplankton counts and biovolume, Site B (9/20/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Aulacoseira sp.*	1.36E+03			229	2.97E+07			9.79E+06
Cocconeis sp.*	3.01E+03			3	8.62E+05	1	2.60E+05	3.69E+05
Fragilaria sp.*	2.03E+03			8	1.55E+06			5.09E+05
Navicula sp.*	1.81E+03			1	1.73E+05			5.69E+04
Chlorophyceae								
Closterium sp.*	1.09E+03	36	3.72E+06	34	3.55E+06	5	4.72E+05	2.59E+06
Coelastrum sp.*	1.24E+04	10	1.17E+07	9	1.06E+07	10	1.07E+07	1.10E+07
Characium sp.*	2.01E+03			10	1.92E+06			6.31E+05
Pediastrum sp.*	3.38E+04	4	1.28E+07	4	1.29E+07	3	8.76E+06	1.15E+07
Scenedesmus sp.*	1.70E+02	4	6.40E+04	4	6.47E+04			4.32E+04
Pandorina sp.*	2.02E+03	1	1.90E+05	2	3.84E+05			1.92E+05
Ankyra sp.*	1.01E+02	6	5.69E+04	3	2.88E+04	3	2.60E+04	3.75E+04
Eudorina sp.*	6.86E+03	12	7.76E+06	5	3.27E+06			3.73E+06
Cryptophyceae								
Cryptomonas sp.*	6.35E+03	3547.064	2.80E+03	3850	1.96E+09	3400	1.74E+09	1.64E+09
Class Chrysophyceae								
Dinobryon sp.*	4.13E+02	6	2.34E+05	9	3.55E+05	20	7.13E+05	4.31E+05
Cyanophyceae								
Anabaena sp.***	8.50E+05	8	1.27E+09	11	1.45E+09	5	5.82E+08	1.10E+09
Aphanizomenon sp.***	2.01E+03	2050	3.89E+08	3000	5.75E+08	3700	6.42E+08	5.33E+08
Oscillatoria sp.***	1.23E+04			1	1.17E+06			3.85E+05
Gomphosphaeria sp.**	3.62E+04			6	2.07E+07	1	3.12E+06	7.83E+06
Dinophyceae								
Ceratium sp.*	5.13E+04	11	5.32E+07	16	7.82E+07	17	7.52E+07	6.87E+07
Peridinium sp.*	2.81E+04	5150	6.88E+09	4502	6.08E+09	4600	5.62E+09	6.20E+09
Euglenophyceae								
Phacus sp.*	4.62E+04	1	4.36E+06					1.49E+06
Synurophyceae								
Mallomonas sp.*	1.61E+03			6	9.20E+05			3.02E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D42. Phytoplankton counts and biovolume, Site B (10/4/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Cocconeis sp.*	4.36E+03	50	1.49E+07		0.00E+00			5.06E+06
Fragilaria sp.*	2.03E+03		0.00E+00		0.00E+00	6	1.15E+06	2.95E+05
Synedra sp.*	7.35E+03	1	5.03E+05	2	1.39E+06	3	2.08E+06	1.27E+06
Chlorophyceae								
Closterium sp.*	1.09E+03	150	1.12E+07	73	7.56E+06	68	7.03E+06	8.67E+06
Coelastrum sp.*	7.03E+03		0.00E+00	1	6.65E+05	3	1.99E+06	7.79E+05
Pediastrum sp.*	5.13E+04	1	3.51E+06	2	9.70E+06		0.00E+00	5.12E+06
Eudorina sp.*	7.89E+03					4	2.98E+06	7.63E+05
Cryptophyceae								
Cryptomonas sp.*	4.11E+03	700	1.97E+08	850	3.30E+08	650	2.52E+08	2.65E+08
Cyanophyceae								
Aphanizomenon sp.***	7.21E+03	38	1.88E+07	9	6.14E+06	200	1.36E+08	4.37E+07
Dinophyceae								
Peridinium sp.*	1.42E+04	1	9.70E+05			2	2.67E+06	1.01E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D43. Phytoplankton counts and biovolume, Site B (10/18/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Cocconeis sp.*	4.36E+03	1	5.49E+05	8	3.70E+06	5	1.84E+06	1.86E+06
Cymbella sp.*	9.01E+03					2	1.52E+06	1.91E+05
Fragilaria sp.*	2.03E+03	275	7.03E+07	214	4.62E+07	118	2.02E+07	5.52E+07
Navicula sp.*	2.11E+03	1	2.66E+05	2	4.49E+05	2	3.56E+05	3.44E+05
Stephanodiscus sp.*	2.11E+04	1	2.66E+06	2	4.48E+06	3	5.34E+06	3.66E+06
Synedra sp.*	7.35E+03	4	3.70E+06			14	8.67E+06	2.98E+06
Unkn. Diatom*	3.57E+03			2	7.58E+05			2.76E+05
Nitzschia sp.*	9.08E+02			2	1.93E+05			7.03E+04
Chlorophyceae								
Closterium sp.*	1.09E+03			15	1.74E+06	12	1.11E+06	7.75E+05
Coelastrum sp.*	7.03E+03	8	7.08E+06	9	6.72E+06	14	8.30E+06	7.11E+06
Characium sp.*	2.01E+03			3	6.41E+05			2.34E+05
Pediastrum sp.*	5.13E+04	4	2.58E+07	5	2.72E+07	3	1.30E+07	2.47E+07
Scenedesmus sp.*	1.70E+02			12	2.16E+05			7.88E+04
Staurastrum sp.*	3.60E+04			1	3.82E+06			1.39E+06
Quadrigulla sp.*	3.98E+02			8	3.38E+05	18	6.04E+05	1.99E+05
Ankyra sp.*	2.20E+02			50	1.17E+06			4.27E+05
Eudorina sp.*	7.89E+03					4	2.66E+06	3.34E+05
Cryptophyceae								
Cryptomonas sp.*	1.89E+03	1304	6.73E+08	1800	7.23E+08	3850	1.31E+09	7.71E+08
Cyanophyceae								
Anabaena sp.***	1.26E+04	100	9.08E+07	252	1.95E+08	200	1.22E+08	1.33E+08
Lyngbya sp.***	2.16E+04			11	2.52E+07			9.19E+06
Gomphosphaeria sp.**	3.51E+04			3	1.12E+07	3	8.89E+06	5.20E+06
Dinophyceae								
Peridinium sp.*	2.81E+04			20	5.67E+07	5	1.07E+07	2.20E+07

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D44. Phytoplankton counts and biovolume, Site B (11/08/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Asterionella sp. *	1.13E+03	79	8.56E+06	78	7.43E+06	400	3.19E+07	1.84E+07
Cocconeis sp.*	4.36E+03	50	2.10E+07	1	3.69E+05	2	6.16E+05	5.41E+06
Fragilaria sp.*	2.03E+03	48	9.38E+06	400	6.88E+07	750	1.08E+08	7.16E+07
Stephanodiscus sp.*	2.11E+04	9	1.83E+07	9	1.61E+07	13	1.94E+07	1.81E+07
Synedra sp.*	7.35E+03	17	1.20E+07	7	4.35E+06	13	6.76E+06	7.24E+06
Chlorophyceae								
Closterium sp.*	1.09E+03	3	3.16E+05			2	1.55E+05	1.43E+05
Pediastrum sp.*	5.13E+04	1	4.94E+06	1	4.34E+06			2.58E+06
Staurastrum sp.*	3.60E+04	1	3.46E+06	1	3.04E+06			1.81E+06
Quadrigulla sp.*	3.98E+02	4	1.53E+05			4	1.13E+05	8.59E+04
Ankyra sp.*	2.20E+02	300	6.37E+06	100	1.87E+06	100	1.56E+06	2.81E+06
Cryptophyceae								
Cryptomonas sp.*	2.82E+03	17900	6.92E+09	18950	6.33E+09	23900	6.63E+09	6.60E+09
Cyanophyceae								
Aphanizomenon sp.***	7.21E+03	100	6.94E+07	300	1.83E+08	4	2.04E+06	7.67E+07

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

D7.5. Phytoplankton abundance and biovolume, Site C (2010)

Table D45. Phytoplankton counts and biovolume, Site C (6/30/2010)

Class/Genus	biovolume per unit μm^3	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	$\mu m^3/L$
Bacillariophyceae								
Asterionella sp. *	1.01E+03	55	3.20E+06	25	1.91E+06	85	5.51E+06	3.32E+06
Aulocoseira sp.*	1.36E+03	600	3.46E+04			1320	1.16E+08	3.10E+07
Fragilaria sp.*	1.88E+03	2880	1.66E+05	1760	2.50E+08	1320	1.59E+08	1.39E+08
Gomphonema sp.*	7.83E+03	2	9.04E+05					3.15E+05
Navicula sp.*	9.97E+02			1	7.56E+04			2.90E+04
Stephanodiscus sp.*	2.01E+04			35	5.34E+07	40	5.18E+07	3.43E+07
Chlorophyceae								
Closterium sp.*	1.09E+03	3	1.90E+05					6.61E+04
Coelastrum sp. *	1.25E+04			2	1.90E+06			7.28E+05
Oocystis sp.*	1.59E+03					9	9.21E+05	2.46E+05
Pediastrum sp.*	5.13E+04	2	5.92E+06	2	7.77E+06	1	3.30E+06	5.93E+06
Staurastrum sp.*	6.77E+03	1	3.91E+05					1.36E+05
Ankyra sp.*	1.01E+02	25	1.45E+05	40	3.05E+05	15	9.72E+04	1.94E+05
Cryptophyceae								
Cryptomonas sp.*	2.37E+03			5520	1.26E+09	5600	5.24E+08	7.84E+08
Cyanophyceae								
Anabaena sp.***	1.71E+04	15	1.48E+07	10	1.29E+07	6	6.59E+06	1.19E+07
Oscillatoria sp.***	1.52E+04	1	8.77E+05					3.06E+05
Dinophyceae								
Peridinium sp.*	1.29E+04	1	7.47E+05					2.60E+05
Euglenophyceae								
Euglena sp.*	2.10E+03	1	1.21E+05					4.22E+04
Synurophyceae								
Mallomonas sp.*	1.61E+03			6	7.31E+05	1	1.04E+05	3.08E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D46. Phytoplankton counts and biovolume, Site C (6/18/2010)

Class/Genus	biovolume per unit µm³	water depth				depth weighted average biovolume
		at the surface		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae						
Asterionella sp.*	1.01E+03	32	3.05E+06	8	7.20E+05	1.05E+06
Aulocoseira sp.*	1.36E+03	17840	2.30E+09	15920	1.94E+09	1.28E+09
Fragilaria sp.*	1.88E+03	50360	8.95E+09	60400	1.01E+10	5.88E+09
Gomphonema sp.*	7.83E+03			2	1.40E+06	4.92E+05
Navicula sp.*	9.97E+02	1	9.45E+04	3	2.67E+05	1.18E+05
Stephanodiscus sp.*	2.01E+04	12	1.52E+08	19	3.41E+07	5.15E+07
Chlorophyceae						
Closterium sp.*	1.09E+03	1	1.04E+05	1	9.77E+04	6.13E+04
Coelastrum sp. *	1.25E+04	7	4.74E+07			1.23E+07
Characium sp.*	1.23E+03	1	4.65E+06			1.21E+06
Oocystis sp.*	1.59E+03			4	5.67E+05	2.00E+05
Pediastrum sp.*	5.13E+04	1	4.86E+06	5	2.29E+07	9.31E+06
Scenedesmus sp.*	1.89E+02	11	5.02E+06	4	6.76E+04	1.33E+06
Staurastrum sp.*	6.77E+03	2	1.28E+06	1	6.05E+05	5.46E+05
Ankyra sp.*	1.01E+02	25	7.62E+05	15	1.35E+05	2.45E+05
Eudorina sp.*	9.09E+02	1	6.89E+06			1.79E+06
Cryptophyceae						
Cryptomonas sp.*	1.61E+03	9880	3.64E+09	5080	1.75E+09	1.56E+09
Chrysophyceae						
Dinobryon sp. *	3.97E+02	10	1.20E+07	18	6.37E+05	3.34E+06
Cyanophyceae						
Anabaena sp.***	2.76E+05			18	7.37E+07	7.97E+08
Dinophyceae						
Ceratium sp.*	8.31E+04	2	6.30E+08	32	2.37E+08	2.47E+08
Peridinium sp.*	1.29E+04	2	9.80E+07	4	4.62E+06	2.70E+07
Euglenophyceae						
Phacus sp.*	4.62E+04	1	4.38E+06	1	4.13E+06	2.59E+06
Synurophyceae						
Mallomonas sp.*	1.61E+03	7	3.05E+07	6	8.61E+05	8.20E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D47. Phytoplankton counts and biovolume, Site C (7/9/2010)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Aulocoseira sp.*	1.36E+03			6.00	1.04E+06			3.77E+05
Fragilaria sp.*	1.88E+03	960.00	2.37E+08	1480.00	3.54E+08	2880.00	4.52E+08	3.60E+08
Stephanodiscus sp.*	2.01E+04	2.00	5.30E+06	3.00	7.70E+06	6.00	1.01E+07	7.97E+06
Chlorophyceae								
Closterium sp.*	1.09E+03			4.00	5.58E+05	3.00	2.75E+05	3.05E+05
Coelastrum sp. *	1.25E+04	1.00	1.65E+06	2.00	3.19E+06			1.59E+06
Characium sp.*	1.23E+03	1.00	1.62E+05					4.27E+04
Scenedesmus sp.*	1.89E+02	4.00	9.98E+04					2.63E+04
Staurastrum sp.*	6.77E+03			1.00	8.64E+05	2.00	1.13E+06	7.37E+05
Ankyra sp.*	1.01E+02					160.00	1.35E+06	5.05E+05
Eudorina sp.*	9.09E+02	4.00	4.79E+05	2.00	2.32E+05			2.10E+05
Cryptomonas								
Cryptomonas sp.*	1.61E+03	9360.00	4.32E+09	7160.00	3.65E+09	3480.00	1.07E+09	2.86E+09
Cyanophyceae								
Anabaena sp.***	2.76E+05	34.00	2.13E+08	42.00	1.57E+08	37.00	9.62E+07	1.49E+08
Aphanizomenon sp.***	7.21E+03	28.00	2.66E+07	9.00	8.28E+06			1.00E+07
Gomphosphearia sp.**	3.51E+04	6.00	2.78E+07					7.34E+06
Dinophyceae								
Ceratium sp.*	8.31E+04	12.00	1.31E+08	7.00	7.42E+07	2.00	1.39E+07	6.67E+07
Peridinium sp.*	1.29E+04	3880.00	6.62E+09	4400.00	7.26E+09	2040.00	2.21E+09	5.19E+09
Euglenophyceae								
Lepocinclis sp.*	1.12E+04					3.00	2.81E+06	1.05E+06
Synurophyceae								
Mallomonas sp.*	1.61E+03	7.00	1.48E+06	10.00	2.05E+06	2.00	269221.19	1.23E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D48. Phytoplankton counts and biovolume, Site C (7/23/2010)

Class/Genus	biovolume per unit μm^3	water depth				depth weighted average biovolume
		at the surface		at the 2 × Secchi depth		
		units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	$\mu m^3/L$
Bacillariophyceae						
Fragilaria sp.*	1.88E+03	1200	2.79E+08	1240	3.24E+08	3.13E+08
Stephanodiscus sp.*	2.01E+04	12	2.99E+07	14	3.92E+07	3.69E+07
Chlorophyceae						
Closterium sp.*	1.09E+03	8	1.08E+06	2	3.04E+05	4.94E+05
Closterium sp.l	1.05E+03	8	1.04E+06	3	4.36E+05	5.82E+05
Characium sp.*	1.23E+03	4	6.08E+05	5	8.53E+05	7.93E+05
Pediastrum sp.*	5.13E+04			1	7.13E+06	5.40E+06
Staurastrum sp.*	6.77E+03	1	8.39E+05			2.04E+05
Cryptophyceae						
Cryptomonas sp.*	1.61E+03	3000	9.84E+07	5360	1.30E+09	1.01E+09
Cyanophyceae						
Anabaena sp.***	2.76E+05	1	6.63E+07	5	1.56E+08	1.34E+08
Aphanizomenon sp.***	7.21E+03	560	5.00E+08	880	8.83E+08	7.90E+08
Microcystis sp.**	1.80E+05	4	8.93E+07	7	1.75E+08	1.55E+08
Lyngbya sp.***	2.16E+04	6	1.60E+07	8	2.40E+07	2.21E+07
Gomphosphearia sp.**	3.51E+04			5	2.44E+07	1.85E+07
Dinophyceae						
Ceratium sp.*	8.31E+04	19	1.96E+08	25	2.89E+08	2.66E+08
Peridinium sp.*	2.74E+04	12562	2.01E+10	15608	2.81E+10	2.62E+10

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D49. Phytoplankton counts and biovolume, Site C (8/6/2010)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Asterionella sp. *	1.01E+03							3.96E+06
Aulocoseira sp.*	1.36E+03			80	1.08E+07			1.84E+08
Fragilaria sp.*	1.88E+03	160	4.18E+07	2000	3.73E+08	480	9.37E+07	2.19E+07
Stephanodiscus sp.*	2.01E+04	11	3.08E+07	4	8.00E+06	14	2.93E+07	
Chlorophyceae								1.44E+06
Closterium sp.*	1.09E+03	8	1.22E+06	8	8.71E+05	18	2.05E+06	5.46E+05
Coelastrum sp. *	1.25E+04					1	1.30E+06	8.19E+06
Pediastrum sp.*	5.13E+04			2	1.02E+07	2	1.07E+07	5.49E+04
Scenedesmus sp.*	1.89E+02			8	1.51E+05			2.46E+05
Staurastrum sp.*	6.77E+03			1	6.74E+05			3.21E+05
Ankyra sp.*	1.01E+02			40	4.00E+05	40	4.19E+05	
Cryptophyceae								3.73E+08
Cryptomonas sp.*	1.61E+03	7280	1.64E+09	10640	1.58E+09	2200	4.54E+08	
Cyanophyceae								2.37E+07
Anabaena sp.***	2.76E+05			8	6.51E+07			8.86E+07
Aphanizomenon sp.***	7.21E+03	80	8.03E+07	80	5.74E+07	160	1.20E+08	7.66E+07
Microcystis sp.**	1.80E+05	4	1.00E+08	6	1.08E+08	2	3.75E+07	5.48E+06
Lyngbya sp.***	2.16E+04			7	1.50E+07			1.36E+07
Gomphosphearia sp.**	3.51E+04	8	3.91E+07	4	1.40E+07			
Dinophyceae								5.35E+08
Ceratium sp.*	8.31E+04	11	1.27E+08	18	1.49E+08	125	1.08E+09	1.20E+10
Peridinium sp.*	2.74E+04	9605	1.73E+10	9967	1.28E+10	6245	8.42E+09	
Euglenophyceae								2.24E+06
Lepocinclis sp.*	1.12E+04	4	6.22E+06	1	1.11E+06	1	1162944	3.96E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D50. Phytoplankton counts and biovolume, Site C (8/20/2010)

Class/Genus	biovolume per unit µm³	water depth				depth weighted average biovolume
		at the surface		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae						
Aulocoseira sp.*	1.36E+03	31	5E+06			1.45E+06
Cocconeis sp.*	4.93E+03	1	6E+05			4.13E+05
Fragilaria sp.*	1.88E+03	1000	2E+08	400	7E+07	1.01E+08
Stephanodiscus sp.*	2.01E+04	24	5E+07	36	7E+07	5.79E+07
Chlorophyceae						
Closterium sp.*	1.07E+03	15	2E+06	20	2E+06	1.68E+06
Coelastrum sp. *	1.25E+04			1	1E+06	4.38E+05
Characium sp.*	1.23E+03	1	1E+05	3	341045	2.69E+05
Pediastrum sp.*	5.13E+04	3	2E+07	5	2E+07	1.41E+07
Scenedesmus sp.*	1.89E+02					2.28E+04
Staurastrum sp.*	6.77E+03			3	2E+06	1.12E+06
Ankyra sp.*	1.01E+02	40	5E+05			3.37E+05
Cryptophyceae						
Cryptomonas sp.*	1.61E+03	38600	4E+09	36600	3E+09	2.40E+09
Cyanophyceae						
Anabaena sp.***	2.76E+05	4	2E+08	4	2E+08	1.10E+08
Aphanizomenon sp.***	7.21E+03	320	3E+08	6	4E+06	5.74E+07
Microcystis sp.**	1.80E+05	2	4E+07	3	5E+07	6.00E+07
Lyngbya sp.***	2.16E+04	240	6E+08	10	2E+07	1.35E+08
Gomphosphearia sp.**	3.51E+04			1	3E+06	1.23E+06
Dinophyceae						
Ceratium sp.*	8.31E+04	120	1E+09	1000	8E+09	4.40E+09
Peridinium sp.*	2.74E+04	6455	1E+10	10937	1E+10	9.94E+09
Euglenophyceae						
Lepocinclis sp.*	1.12E+04	5	6E+06	1	1E+06	2.04E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D51. Phytoplankton counts and biovolume, Site C (9/3/2010)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Aulocoseira sp.*	1.36E+03	15	1E+06	13	2E+06			1.09E+06
Cocconeis sp.*	4.93E+03	3	1E+06	2	1E+06			6.71E+05
Cymbella sp.*	9.01E+03			1	1E+06			3.59E+05
Fragilaria sp.*	1.88E+03	4400	5E+08	1600	3E+08	720	2E+08	3.26E+08
Stephanodiscus sp.*	2.01E+04	25	3E+07	15	3E+07	8	2E+07	2.75E+07
Chlorophyceae								
Closterium sp.*	1.07E+03	15	1E+06	9	1E+06	5	6E+05	9.05E+05
Coelastrum sp. *	1.25E+04	5	4E+06	3	4E+06	1	1E+06	3.14E+06
Characium sp.*	1.23E+03			1	1E+05	4	5E+05	2.33E+05
Oocystis sp.*	1.59E+03					12	2E+06	7.16E+05
Pediastrum sp.*	5.13E+04	1	3E+06	3	2E+07	1	6E+06	9.01E+06
Scenedesmus sp.*	1.89E+02	8	99188					2.85E+04
Staurastrum sp.*	6.77E+03	20	9E+06	12	9E+06	18	1E+07	1.04E+07
Quadrigullasp.*	2.75E+02	10	2E+05	7	2E+05			1.28E+05
Ankyra sp.*	1.01E+02	40	3E+05	40	4E+05			2.36E+05
Cryptophyceae								
Cryptomonas sp.*	1.61E+03	9120	1E+09	4680	1E+09	4960	1E+09	1.31E+09
Cyanophyceae								
Anabaena sp.***	2.76E+05	8	2E+08	7	4E+08	4	2E+08	2.81E+08
Aphanizomenon sp.***	7.21E+03	25	1E+07	35	3E+07	39	3E+07	2.40E+07
Microcystis sp.**	1.80E+05	9	1E+08	3	6E+07	5	1E+08	8.59E+07
Gomphosphearia sp.**	3.51E+04	5	1E+07	2	7E+06	1	4E+06	7.43E+06
Dinophyceae								
Ceratium sp.*	8.31E+04	1000	5E+09	150	1E+09	35	3E+08	2.17E+09
Peridinium sp.*	2.74E+04	12125	1E+10	8246	1E+10	7403	1E+10	1.08E+10
Euglenophyceae								
Lepocinclis sp.*	1.12E+04			1	1E+06			4.44E+05
Phacus sp.*	4.62E+04	1	3E+06	1	5E+06			2.71E+06
Synurophyceae		12125						
Mallomonas sp.*	1.61E+03	3	3E+05					9.08E+04

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D52. Phytoplankton counts and biovolume, Site C (9/17/2010)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Aulocoseira sp.*	1.36E+03	6	3.27E+05	12	1.87E+06	7	1.08E+06	1.20E+06
Cocconeis sp.*	4.93E+03	2	3.94E+05					8.82E+04
Cymbella sp.*	9.01E+03	1	3.61E+05			1	1.02E+06	4.95E+05
Fragilaria sp.*	1.88E+03	880	6.60E+07	2080	4.46E+08	3400	7.20E+08	4.72E+08
Navicula sp.*	9.97E+02					1	1.12E+05	4.59E+04
Stephanodiscus sp.*	2.01E+04	8	6.44E+06	10	2.30E+07	12	2.72E+07	2.10E+07
Chlorophyceae								
Closterium sp.*	1.07E+03	14	6.09E+05	13	1.62E+06	14	1.73E+06	1.44E+06
Coelastrum sp. *	1.25E+04	2	1.00E+06	1	1.43E+06			7.50E+05
Characium sp.*	1.23E+03			1	1.40E+05	2	2.77E+05	1.64E+05
Oocystis sp.*	1.59E+03	12	7.63E+05					1.71E+05
Pediastrum sp.*	5.13E+04	1	2.05E+06			5	2.89E+07	1.23E+07
Scenedesmus sp.*	1.89E+02	12	9.08E+04	4	8.64E+04			5.22E+04
Staurastrum sp.*	6.77E+03	4	1.08E+06	4	3.09E+06	2	1.53E+06	2.01E+06
Quadrigullasp.*	2.75E+02			4	1.26E+05			4.63E+04
Ankyra sp.*	1.01E+02	160	6.44E+05	2	2.30E+04	2	2.27E+04	1.62E+05
Eudorina sp.*	9.09E+02	4	1.45E+05					3.25E+04
Cryptophyceae								
Cryptomonas sp.*	1.61E+03	4480	3.41E+08	7640	2.80E+09	4840	1.54E+09	1.73E+09
Cyanophyceae								
Anabaena sp.***	2.76E+05	11	1.32E+08	5	3.06E+08			1.42E+08
Aphanizomenon sp.***	7.21E+03	4	1.15E+06	10	8.24E+06	9	7.32E+06	6.28E+06
Microcystis sp.**	1.80E+05	3	2.16E+07					4.84E+06
Lyngbya sp.***	2.16E+04	5	4.31E+06	1	2.46E+06	4	9.73E+06	5.84E+06
Gomphosphearia sp.**	3.51E+04	6	8.43E+06	6	2.41E+07	4	1.59E+07	1.72E+07
Dinophyceae								
Ceratium sp.*	8.31E+04	59	1.96E+08	42	3.99E+08	48	4.50E+08	3.74E+08
Peridinium sp.*	2.74E+04	8483	4.39E+09	8040	1.19E+10	5480	7.99E+09	8.62E+09
Gymnodinium sp.*	1.97E+03	2	1.57E+05					3.52E+04
Euglenophyceae								
Lepocinclis sp.*	1.12E+04	3	1.34E+06					3.00E+05
Synurophyceae								
Mallomonas sp.*	1.61E+03	640	4.12E+07	15	2753455	5	9.07E+05	1.06E+07

Table D53. Phytoplankton counts and biovolume, Site C (10/1/2010)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Asterionella sp. *	1.01E+03					1	9.95E+04	2.95E+04
Cocconeis sp.*	4.93E+03	1	2.96E+05	1	4.10E+05			2.47E+05
Fragilaria sp.*	1.88E+03	3760	4.23E+08	3520	5.49E+08	3920	7.26E+08	5.56E+08
Navicula sp.*	9.97E+02	1	5.98E+04					2.15E+04
Stephanodiscus sp.*	2.01E+04	15	1.81E+07	19	3.18E+07	15	2.98E+07	2.63E+07
Synedra sp.*	1.42E+04			1	1.18E+06	2	2.80E+06	1.24E+06
Chlorophyceae								
Closterium sp.*	1.09E+03	10	6.57E+05	11	1.00E+06	7	7.56E+05	8.05E+05
Characium sp.*	1.23E+03			1	1.02E+05	1	1.21E+05	7.10E+04
Oocystis sp.*	1.59E+03	2	1.91E+05					6.85E+04
Pediastrum sp.*	5.13E+04			1	4.27E+06			1.47E+06
Scenedesmus sp.*	1.89E+02	4	4.54E+04			4	7.47E+04	3.85E+04
Staurastrum sp.*	6.77E+03	5	2.03E+06	2	1.13E+06	1	6.69E+05	1.32E+06
Quadrigullasp.*	2.75E+02	8	1.32E+05	4	9.15E+04	8	2.17E+05	1.43E+05
Cryptophyceae								
Cryptomonas sp.*	1.61E+03	21200	4.80E+09	20000	6.26E+09	13760	5.23E+09	5.43E+09
Cyanophyceae								
Anabaena sp.***	2.76E+05	4	4.09E+06	1	4.45E+07	4	2.11E+08	7.95E+07
Aphanizomenon sp.***	7.21E+03	26	1.13E+07	5	3.00E+06	4	2.85E+06	5.92E+06
Microcystis sp.**	1.80E+05	1	1.08E+07			1	1.78E+07	9.17E+06
Lyngbya sp.***	2.16E+04	15	1.94E+07	33	5.92E+07	16	3.41E+07	3.74E+07
Gomphosphearia sp.**	3.51E+04	240	5.06E+08	12	3.51E+07	6	2.08E+07	2.00E+08
Dinophyceae								
Ceratium sp.*	8.31E+04	3	1.50E+07	2	1.38E+07	1	8.20E+06	1.26E+07
Peridinium sp.*	1.29E+04	2520	1.96E+09	2040	2.19E+09	1440	1.84E+09	2.00E+09
Synurophyceae								
Mallomonas sp.*	1.61E+03	1	9.65E+04	1	1.34E+05			8.06E+04

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

D7.6. Phytoplankton abundance and biovolume, Site C (2011)

Table D54. Phytoplankton counts and biovolume, Site C (6/30/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Asterionella sp. *	1.22E+03	120	1.14E+07	110	1.68E+07	145	2.16E+07	1.70E+07
Cocconeis sp.*	1.29E+04	2	2.01E+06	4	6.47E+06	2	3.16E+06	4.12E+06
Fragilaria sp.*	1.88E+03	1900	2.77E+08	4600	1.08E+09	10350	2.37E+09	1.30E+09
Stephanodiscus sp.*	2.18E+04	6	1.01E+07	12	3.27E+07	10	2.66E+07	2.45E+07
Synedra sp*	1.32E+04	1	1.02E+06					2.79E+05
Class Chlorophyceae								
Closterium sp.*	1.55E+03	2	2.41E+05	2	3.88E+05	1	1.89E+05	2.80E+05
Coelastrum sp.*	6.73E+03			10	8.41E+06	1	8.22E+05	3.53E+06
Oocystis sp.*	1.49E+03			1	1.86E+05			7.19E+04
Pediastrum sp.*	1.08E+04			3	4.05E+06	1	1.32E+06	2.02E+06
Staurastrum sp.*	3.85E+04			1	4.82E+06	3	1.41E+07	6.67E+06
Cryptophyceae								
Cryptomonas sp.	1.76E+03	13700	1.41E+09	18650	1.03E+09	915	3.52E+08	9.03E+08
Chrysophyceae								
Dinobryon sp.*	2.96E+02	45	1.04E+06	36	1.33E+06	12	4.34E+05	9.45E+05
Cyanophyceae								
Anabaena sp.*	8.49E+05	33	1.36E+08	9	2.06E+06	2	4.47E+05	3.81E+07
Aphanizomenon sp.*	3.32E+03	12	3.10E+06	11	4.57E+06	2	8.12E+05	2.89E+06
Microcystis sp.*	6.99E+04							
Gomphosphaeria sp.*	1.53E+04	1	1.19E+06	1	1.91E+06			1.06E+06
Dinophyceae								
Ceratium sp.*	9.24E+04	19	1.36E+08	16	1.85E+08	13	1.47E+08	1.59E+08
Peridinium sp.*	3.37E+04	27	1.52E+08	20	2.00E+08	13	1.47E+08	1.69E+08

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D55. Phytoplankton counts and biovolume, Site C (7/13/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Cocconeis sp.*	1.E+04	3	5.E+06	4	4.E+06	1	1.E+06	3.E+06
Fragilaria sp.*	2.E+03	1333	3.E+08	762	1.E+08	150	3.E+07	1.E+08
Navicula sp.*	1.E+03	1	1.E+05			1	1.E+05	9.E+04
Stephanodiscus sp.*	2.E+04	4	1.E+07	4	7.E+06	3	7.E+06	8.E+06
Synedra sp.*	1.E+04			1	1.E+06			3.E+05
Chlorophyceae								
Closterium sp.*	2.E+03	5	1.E+06			11	2.E+06	1.E+06
Cosmarium sp.*	2.E+04	1	3.E+06			3	7.E+06	4.E+06
Characium sp.*	1.E+03	1	2.E+05	4	4.E+05			2.E+05
Pediastrum sp.*	1.E+04	4	5.E+06	10	9.E+06	4	5.E+06	6.E+06
Staurastrum sp.*	4.E+04	2	1.E+07	5	2.E+07	4	2.E+07	1.E+07
Ankyra sp.*	3.E+02			1	3.E+04			7.E+03
Cryptophyceae								
Cryptomonas sp.*	2.E+03	9714	4.E+09	13714.3	2.E+09	2300	7.E+08	2.E+09
Chrysophyceae								
Dinobryon sp.*	3.E+02	10	4.E+05	5	1.E+05	1	3.E+04	2.E+05
Cyanophyceae								
Anabaena sp.*	8.E+05	96	2.E+08	19	1.E+09	14	5.E+08	6.E+08
Aphanizomenon sp.*	3.E+03	11905	5.E+09	15523.8	4.E+09	9650	3.E+09	4.E+09
Microcystis sp.*	7.E+04	2	2.E+07	3	2.E+07			9.E+06
Gomphosphaeria sp.*	2.E+04	3	6.E+06	8	1.E+07	24	4.E+07	2.E+07
Dinophyceae								
Ceratium sp.*	9.E+04			4	3.E+07	5	5.E+07	3.E+07
Peridinium sp.*	3.E+04	10	3.E+07	1	3.E+06	15	4.E+07	3.E+07

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D56. Phytoplankton counts and biovolume, Site C (7/20/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Cocconeis sp.*	1.E+04	1	1.E+06	9	1.E+07	12	2.E+07	1.E+07
Fragilaria sp.*	2.E+03	55	1.E+07	89	2.E+07	30	7.E+06	1.E+07
Navicula sp.*	1.E+03			2	2.E+05			5.E+04
Chlorophyceae								
Closterium sp.*	2.E+03			2	3.E+05	1	2.E+05	2.E+05
Coelastrum sp. *	7.E+03			1	7.E+05	3	3.E+06	2.E+06
Characium sp.*	1.E+03	1	1.E+05					3.E+04
Pediastrum sp.*	1.E+04	7	8.E+06	9	1.E+07	4	5.E+06	7.E+06
Staurastrum sp.*	4.E+04	2	8.E+06					1.E+06
Ankyra sp.*	3.E+02			2	7.E+04			2.E+04
Cryptophyceae								
Cryptomonas sp.*	2.E+03	4000	2.E+09	4550	9.E+08	400	3.E+07	6.E+08
Cyanophyceae								
Anabaena sp.*	8.E+05	15	2.E+09	8	9.E+08	13	1.E+09	1.E+09
Aphanizomenon sp.*	3.E+03	38810	1.E+10	29600	1.E+10	4150	2.E+09	6.E+09
Microcystis sp.*	7.E+04			4	3.E+07			7.E+06
Gomphosphaeria sp.*	2.E+04			4	6.E+06	2	4.E+06	4.E+06
Dinophyceae								
Ceratium sp.*	9.E+04	1	1.E+07	6	6.E+07			2.E+07
Peridinium sp.*	3.E+04	143	4.E+08	262	7.E+08	6	2.E+07	3.E+08
Euglenophyceae								
Euglena sp.*	3.E+03					1	4.E+05	2.E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D57. Phytoplankton counts and biovolume, Site C (7/27/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Cocconeis sp.*	1.E+04	20	2.E+07	18	3.E+07	21	3.E+07	3.E+07
Fragilaria sp.*	2.E+03	40	7.E+06	41	8.E+06	54	1.E+07	9.E+06
Stephanodiscus sp.*	2.E+04			1	2.E+06	2	4.E+06	3.E+06
Chlorophyceae								
Closterium sp.*	9.E+04	6	9.E+05	7	1.E+06	9	2.E+07	1.E+07
Coelastrum sp. *	7.E+03	2	1.E+06	1	7.E+05	2	1.E+06	1.E+06
Characium sp.*	1.E+03	1	1.E+05			1	1.E+05	1.E+05
Oocystis sp.*	1.E+03					6	9.E+05	5.E+05
Pediastrum sp.*	1.E+04	7	7.E+06	7	8.E+06			3.E+06
Scenedesmus sp.*	8.E+01	4	3.E+04					5.E+03
Eudorina sp.*	8.E+03	5	4.E+06	2	2.E+06			1.E+06
Cryptophyceae								
Cryptomonas sp.*	2.E+03	1100	2.E+08	400	1.E+08	200	3.E+07	7.E+07
Chrysophyceae								
Dinobryon sp.*	3.E+02	1	3.E+04					5.E+03
Cyanophyceae								
Anabaena sp.*	8.E+05	46	3.E+09	52	3.E+09	50	4.E+09	4.E+09
Aphanizomenon sp.*	3.E+03	34350	1.E+10	24550	9.E+09	12900	4.E+09	7.E+09
Microcystis sp.*	7.E+04	19	1.E+08	20	2.E+08	6	4.E+07	8.E+07
Oscillatoria sp.*	1.E+04					1	1.E+06	7.E+05
Gomphosphaeria sp.*	2.E+04			2	3.E+06			9.E+05
Dinophyceae								
Ceratium sp.*	9.E+04	7	6.E+07	10	1.E+08	5	5.E+07	6.E+07
Peridinium sp.*	3.E+04	5760	1.E+10	4275	1.E+10	1403	4.E+09	7.E+09
Euglenophyceae								
Lepocinclis sp.*	7556	2	1.E+06	1	8.E+03	1	7.E+05	7.E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D58. Phytoplankton counts and biovolume, Site C (8/03/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Cocconeis sp.*	1.E+04	5	7.E+06	4	6.E+06	1	1.E+06	3.E+06
Fragilaria sp.*	2.E+03	12	2.E+06			24	5.E+06	3.E+06
Navicula sp.*	1.E+03			1	1.E+05	1	1.E+05	9.E+04
Synedra sp.*	1.E+04			1	1.E+06			4.E+05
Unkn. Diatom*	1.E+03	45	5.E+06	36	4.E+06	15	2.E+06	3.E+06
Chlorophyceae								
Closterium sp.*	2.E+03	27	5.E+06	23	4.E+06	24	4.E+06	4.E+06
Coelastrum sp. *	7.E+03	5	4.E+06	5	4.E+06	3	2.E+06	3.E+06
Characium sp.*	1.E+03			1	1.E+05	1	1.E+05	1.E+05
Oocystis sp.*	1.E+03					18	3.E+06	2.E+06
Pediastrum sp.*	1.E+04	14	2.E+07	21	2.E+07	18	2.E+07	2.E+07
Scenedesmus sp.*	8.E+01			4	4.E+04	4	3.E+04	3.E+04
Staurastrum sp.*	4.E+04	4	2.E+07	7	3.E+07	1	4.E+06	1.E+07
Pandorina sp.*	2.E+03	5	1.E+06	13	3.E+06	10	2.E+06	2.E+06
Eudorina sp.*	8.E+03	1	9.E+05	9	8.E+06	9	7.E+06	6.E+06
Cryptophyceae								
Cryptomonas sp.*	2.E+03	2250	1.E+09	3400	2.E+09	5800	2.E+09	2.E+09
Cyanophyceae								
Anabaena sp.*	4.E+05	2619	2.E+09	4507	3.E+09	2720	2.E+09	2.E+09
Microcystis sp.*	7.E+04	19	1.E+08	11	9.E+07	10	7.E+07	9.E+07
Oscillatoria sp.*	1.E+04			1	1.E+06	9	1.E+07	7.E+06
Lyngbya sp.*	3.E+03					1	3.E+05	2.E+05
Gomphosphaeria sp.*	2.E+04	5	8.E+06	17	3.E+07	12	2.E+07	2.E+07
Dinophyceae								
Ceratium sp.*	9.E+04	5	5.E+07	4	4.E+07	17	2.E+08	1.E+08
Peridinium sp.*	3.E+04	6615	2.E+10	6620	2.E+10	2405	6.E+09	1.E+10
Euglenophyceae								
Euglena sp.*	3.E+03	1	3.E+05					5.E+04
Lepocinclis sp.*	8.E+03	3	2490122	2	2.E+06	7	5.E+06	4.E+06
Phacus sp.*	5.E+04					1	5.E+06	3.E+06
Synurophyceae								
Mallomonas sp.*	2.E+03			2	4.E+05			1.E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D59. Phytoplankton counts and biovolume, Site C (8/17/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Cocconeis sp.*	1.E+04	5	7.E+06	4	6.E+06	1	1.E+06	3.E+06
Fragilaria sp.*	2.E+03	12	2.E+06			24	5.E+06	3.E+06
Navicula sp.*	1.E+03			1	1.E+05	1	1.E+05	9.E+04
Synedra sp.*	1.E+04			1	1.E+06			4.E+05
Unkn. diatom*	1.E+03	45	5.E+06	36	4.E+06	15	2.E+06	3.E+06
Chlorophyceae								
Closterium sp.*	2.E+03	27	5.E+06	23	4.E+06	24	4.E+06	4.E+06
Coelastrum sp. *	7.E+03	5	4.E+06	5	4.E+06	3	2.E+06	3.E+06
Characium sp.*	1.E+03			1	1.E+05	1	1.E+05	1.E+05
Oocystis sp.*	1.E+03					18	3.E+06	2.E+06
Pediastrum sp.*	1.E+04	14	2.E+07	21	2.E+07	18	2.E+07	2.E+07
Scenedesmus sp.*	8.E+01			4	4.E+04	4	3.E+04	3.E+04
Staurastrum sp.*	4.E+04	4	2.E+07	7	3.E+07	1	4.E+06	1.E+07
Pandorina sp.*	2.E+03	5	1.E+06	13	3.E+06	10	2.E+06	2.E+06
Eudorina sp.*	8.E+03	1	9.E+05	9	8.E+06	9	7.E+06	6.E+06
Cryptophyceae								
Cryptomonas sp.*	2.E+03	2250	1.E+09	3400	2.E+09	5800	2.E+09	2.E+09
Cyanophyceae								
Anabaena sp.*	4.E+05	2619	2.E+09	4507	3.E+09	2720	2.E+09	2.E+09
Microcystis sp.*	7.E+04	19	1.E+08	11	9.E+07	10	7.E+07	9.E+07
Oscillatoria sp.*	1.E+04			1	1.E+06	9	1.E+07	7.E+06
Lyngbya sp.*	3.E+03					1	3.E+05	2.E+05
Gomphosphaeria sp.*	2.E+04	5	8.E+06	17	3.E+07	12	2.E+07	2.E+07
Dinophyceae								
Ceratium sp.*	9.E+04	5	5.E+07	4	4.E+07	17	2.E+08	1.E+08
Peridinium sp.*	3.E+04	6615	2.E+10	6620	2.E+10	2405	6.E+09	1.E+10
Euglenophyceae								
Euglena sp.*	3.E+03	1	3.E+05					5.E+04
Lepocinclis sp.*	8.E+03	3	2490122	2	2.E+06	7	5.E+06	4.E+06
Phacus sp.*	5.E+04					1	5.E+06	3.E+06
Synurophyceae								
Mallomonas sp.*	2.E+03			2	4.E+05			1.E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D60. Phytoplankton counts and biovolume, Site C (8/30/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Aulacoseira sp.*	1.E+03					32	4.E+06	2.E+06
Cocconeis sp.*	1.E+04			2	3.E+06	7	9.E+06	5.E+06
Chlorophyceae								
Closterium sp.*	2.E+03	12	2.E+06	15	2.E+06	22	3.E+06	3.E+06
Coelastrum sp. *	7.E+03	12	9.E+06	15	1.E+07	12	8.E+06	9.E+06
Characium sp.*	1.E+03					5	7.E+05	4.E+05
Oocystis sp.*	1.E+03					1	1.E+05	8.E+04
Pediastrum sp.*	1.E+04	14	2.E+07	4	5.E+06	5	5.E+06	7.E+06
Scenedesmus sp.*	8.E+01	16	1.E+05	8	7.E+04	32	3.E+05	2.E+05
Ankyra sp.*	3.E+02					2	7.E+04	4.E+04
Pandorina sp.*	2.E+03	25	5.E+06	30	6.E+06	40	8.E+06	7.E+06
Cryptophyceae								
Cryptomonas sp.*	3.E+03	1800	8.E+08	2350	9.E+08	3450	1.E+09	9.E+08
Chrysophyceae								
Dinobryon sp.*	3.E+02	5	2.E+05	12	4.E+05	6	2.E+05	2.E+05
Cyanophyceae								
Anabaena sp.*	8.E+05	33	2.E+09	30	3.E+09	42	5.E+09	4.E+09
Aphanizomenon sp.*	3.E+03	1050	4.E+08	1400	5.E+08	600	2.E+08	3.E+08
Microcystis sp.*	7.E+04					13	9.E+07	5.E+07
Oscillatoria sp.*	1.E+04					2	2.E+06	1.E+06
Lyngbya sp.*	3.E+03					5	1.E+06	8.E+05
Gomphosphaeria sp.*	2.E+04	8	1.E+07	40	6.E+07	38	6.E+07	5.E+07
Dinophyceae								
Ceratium sp.*	9.E+04	11	1.E+08	9	9.E+07	14	1.E+08	1.E+08
Peridinium sp.*	3.E+04	8250	2.E+10	7750	2.E+10	7956	2.E+10	2.E+10
Euglenophyceae								
Euglena sp.*	3.E+03					1	3.E+05	2.E+05
Lepocinclis sp.*	8.E+03					1	7.E+05	4.E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D61. Phytoplankton counts and biovolume, Site C (9/20/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Aulacoseira sp.*	1.E+03	82	1.E+07	120	2.E+07	56	7.E+06	1.E+07
Cocconeis sp.*	1.E+04	2	3.E+06	6	9.E+06	4	5.E+06	6.E+06
Cymbella sp.*	1.E+04					5	7.E+06	2.E+06
Navicula sp.*	1.E+03			3	4.E+05			1.E+05
Cyclotella sp.*	9.E+02	500	4.E+07					1.E+07
Chlorophyceae								
Closterium sp.*	2.E+03	23	4.E+06	24	4.E+06	15	2.E+06	4.E+06
Coelastrum sp. *	7.E+03	10	7.E+06	12	1.E+07	12	8.E+06	8.E+06
Characium sp.*	1.E+03	7	1.E+06	4	6.E+05	3	4.E+05	7.E+05
Pediastrum sp.*	1.E+04			7	9.E+06	4	4.E+06	5.E+06
Staurastrum sp.*	4.E+04					1	4.E+06	1.E+06
Ankyra sp.*	3.E+02			250	1.E+07	100	3.E+06	5.E+06
Pandorina sp.*	2.E+03	1	2.E+05			5	1.E+06	4.E+05
Cryptophyceae								
Cryptomonas sp.*	2.E+03	600	4.E+07	3700	2.E+09	2600	1.E+09	1.E+09
Chrysophyceae								
Dinobryon sp.*	3.E+02	450	1.E+07	300	1.E+07	350	1.E+07	1.E+07
Cyanophyceae								
Anabaena sp.*	8.E+05	9	1.E+09	103	6.E+08	13	2.E+09	1.E+09
Aphanizomenon sp.*	3.E+03	2000	7.E+08	2100	8.E+08	3650	1.E+09	9.E+08
Microcystis sp.*	7.E+04					1	7.E+06	2.E+06
Oscillatoria sp.*	1.E+04			3	4.E+06	2	2.E+06	2.E+06
Lyngbya sp.*	3.E+03					1	3.E+05	9.E+04
Gomphosphaeria sp.*	2.E+04	2	3.E+06	3	6.E+06	3	5.E+06	4.E+06
Dinophyceae								
Ceratium sp.*	9.E+04	19	2.E+08	21	2.E+08	13	1.E+08	2.E+08
Peridinium sp.*	3.E+04	3752	1.E+10	4253	1.E+10	3201	8.E+09	1.E+10
Euglenophyceae								
Euglena sp.*	3.E+03	1	3.E+05					9.E+04
Synurophyceae								
Mallomonas sp.*	2.E+03	12	2.E+06	3	6.E+05			8.E+05

enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D62. Phytoplankton counts and biovolume, Site C (10/4/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Asterionella sp.	1.22E+03	13	1.49E+06					4.46E+05
Aulacoseira sp.*	1.22E+03			18	1.75E+06			6.68E+05
Cocconeis sp.*	1.29E+04	6	7.30E+06	9	9.26E+06			5.71E+06
Cymbella sp.*	1.42E+04	1	1.34E+06					3.99E+05
Fragilaria sp.*	1.88E+03	10	1.76E+06			40	8.30E+06	3.18E+06
Navicula sp.*	1.07E+03	1	1.00E+05					2.99E+04
Stephanodiscus sp.*	2.18E+04			1	1.73E+06			6.62E+05
Synedra sp.*	1.32E+04			1	1.05E+06			4.01E+05
Chlorophyceae								
Closterium sp.*	1.55E+03	10	1.46E+06	17	2.10E+06	8	1.37E+06	1.68E+06
Coelastrum sp. *	6.73E+03	7	4.43E+06	10	5.36E+06	3	2.23E+06	4.08E+06
Characium sp.*	1.36E+03			1	1.08E+05			4.12E+04
Oocystis sp.*	1.49E+03	8	1.12E+06	2	2.37E+05	2	3.30E+05	5.30E+05
Pediastrum sp.*	1.08E+04			1	8.60E+05	1	1.20E+06	7.11E+05
Eudorina sp.*	7.89E+03			1	7.42E+05			2.83E+05
Cryptophyceae								
Cryptomonas sp.*	2.59E+03	1450	5.49E+08	1750	5.98E+08	850	4.14E+08	5.24E+08
Cyanophyceae								
Aphanizomenon sp.*	3.32E+03	4	1.25E+06	100	2.65E+07	1	3.68E+05	1.06E+07
Oscillatoria sp.*	1.23E+04	1	1.16E+06					3.45E+05
Gomphosphaeria sp.*	1.53E+04	2	2.88E+06	1	1.22E+06			1.32E+06
Dinophyceae								
Peridinium sp.*	3.37E+04	6	1.59E+07	53	1.73E+08	4	1.13E+07	7.45E+07

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D63. Phytoplankton counts and biovolume, Site C (10/18/2011)

Class/Genus	biovolume per unit µm³	water depth				depth weighted average biovolume
		at the surface		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae						
Aulacoseira sp.*	1.E+03			24	3.E+06	1.E+06
Cocconeis sp.*	1.E+04	4	3.E+06	9	1.E+07	7.E+06
Fragilaria sp.*	2.E+03	98	9.E+06	78	2.E+07	1.E+07
Navicula sp.*	1.E+03	100	5.E+06	3	3.E+05	3.E+06
Stephanodiscus sp.*	2.E+04			1	2.E+06	1.E+06
Synedra sp.*	1.E+04	7	5.E+06	10	1.E+07	9.E+06
Unkn. diatom*	1.E+03			3	3.E+05	2.E+05
Cyclotella sp.*	9.E+02	37	2.E+06			9.E+05
Chlorophyceae						
Closterium sp.*	2.E+03	12	9.E+05	18	3.E+06	2.E+06
Coelastrum sp. *	7.E+03	3	1.E+06	11	8.E+06	4.E+06
Pediastrum sp.*	1.E+04	2	1.E+06	4	5.E+06	3.E+06
Scenedesmus sp.*	8.E+01	8	3.E+04			2.E+04
Staurastrum sp.*	4.E+04			1	4.E+06	2.E+06
Quadrigulla sp.*	3.E+02	22	3.E+05			2.E+05
Ankyra sp.*	3.E+02	200	3.E+06	100	4.E+06	4.E+06
Cryptophyceae						
Cryptomonas sp.*	3.E+03	4850	1.E+09	3950	2.E+09	1.E+09
Cyanophyceae						
Anabaena sp.*	2.E+03	1	9.E+04			5.E+04
Aphanizomenon sp.*	3.E+03	500	8.E+07	200	7.E+07	8.E+07
Gomphosphaeria sp.*	2.E+04	1	8.E+05	2	3.E+06	2.E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D64. Phytoplankton counts and biovolume, Site C (10/04/2011)

Class/Genus	biovolume per unit μm^3	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	$\mu m^3/L$
Bacillariophyceae								
Asterionella sp.	1.E+03	45	4.E+06	16	2.E+06	43	5.E+06	3.E+06
Fragilaria sp.*	2.E+03	550	8.E+07	800	1.E+08	1950	3.E+08	2.E+08
Stephanodiscus sp.*	2.E+04	6	1.E+07	4	8.E+06	2	4.E+06	7.E+06
Synedra sp.*	1.E+04	15	1.E+07	12	2.E+07	6	7.E+06	1.E+07
Chlorophyceae								
Closterium sp.*	2.E+03	2	2.E+05			3	4.E+05	2.E+05
Coelastrum sp. *	7.E+03	1	5.E+05	1	6.E+05			4.E+05
Pediastrum sp.*	1.E+04	1	8.E+05					2.E+05
Scenedesmus sp.*	8.E+01	4	3.E+04					7.E+03
Ankyra sp.*	3.E+02	150	4.E+06	250	8.E+06			4.E+06
Cryptophyceae								
Cryptomonas sp.*	3.E+03	22900	7.E+09	16300	6.E+09	20500	8.E+09	7.E+09
Class Cyanophyceae								
Aphanizomenon sp.*	3.E+03	42	1.E+07	42	1.E+07	22	6.E+06	1.E+07

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

D7.6. Phytoplankton abundance and biovolume, Site D (2010)

Table D65. Phytoplankton counts and biovolume, Site D (6/4/2010)

Class/Genus	biovolume per unit μm^3	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	units/ml	$\mu m^3/L$	$\mu m^3/L$
Bacillariophyceae								
Asterionella sp.*	1.01E+03	65	5.49E+06	17	1.54E+06	32	2.49E+06	3.01E+06
Aulocoseira sp.*	1.36E+03			18	2.21E+06	14	1.47E+06	1.32E+06
Fragilaria sp.*	1.88E+03	1080	1.70E+08	2600	4.39E+08	1680	2.43E+08	2.98E+08
Stephanodiscus sp.*	2.01E+04	50	8.43E+07	1	1.81E+06	8	1.24E+07	2.97E+07
Chlorophyceae								
Closterium sp. *	1.82E+05	1	1.52E+07					4.53E+06
Coelastrum sp.*	1.25E+04	8	8.39E+06					2.50E+06
Pediastrum sp.*	1.51E+04	1	1.26E+06					3.76E+05
Ankyra	1.01E+02	80	6.75E+05	1	9.05E+03	1	7.77E+03	2.07E+05
Cryptophyceae								
Cryptomonas sp.*	2.37E+03	2760	7.25E+08	4760	1.11E+09	7440	2.41E+09	1.40E+09
Chrysophyceae								
Dinobryon sp.*	3.97E+02							
Cyanophyceae								
Anabaena sp.*	1.71E+04	1	1.43E+06	1	1.54E+06	1	1.32E+06	1.44E+06
Aphanizomenon sp.	7.21E+03			1	6.49E+05			2.56E+05
Dinophyceae								
Ceratium sp.*	8.31E+04		2.79E+07		1.50E+07			1.42E+07
Peridinium sp.	1.29E+04	1	1.08E+06	1	1.16E+06			7.81E+05
Synurophyceae								
Mallomonas sp.	1.61E+03	5	673820	6	8.68E+05	4	4.96E+05	6.96E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D66. Phytoplankton counts and biovolume, Site D (6/18/2010)

Class/Genus	biovolume per unit µm³	water depth				depth weighted average biovolume
		at the surface		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae						
Asterionella sp. *	1.E+03	35	3.E+06	26	3.E+06	2.E+06
Aulocoseira sp.*	1.E+03	21640	3.E+09	10960	2.E+09	1.E+09
Cymbella sp.*	9.E+03			1	9.E+05	4.E+05
Fragilaria sp.*	2.E+03	61600	1.E+10	49200	9.E+09	6.E+09
Navicula sp.*	1.E+03	8	8.E+05	7	7.E+05	4.E+05
Stephanodiscus sp.	2.E+04	8	2.E+07	6	1.E+07	8.E+06
Chlorophyceae						
Closterium sp.*	9.E+04	6	7.E+05	3	2.E+07	7.E+06
Coelastrum sp.*	1.E+04	1	1.E+06			2.E+05
Characium sp.*	1.E+03			1	1.E+05	5.E+04
Pediastrum sp.*	2.E+04	1	1.E+06	1	2.E+06	9.E+05
Scenedesmus sp.*	2.E+02	18	3.E+05	8	2.E+05	1.E+05
Staurastrum sp.*	3.E+04	2	7.E+06	6	2.E+07	9.E+06
Ankyra sp*	1.E+02	25	2.E+05	20	2.E+05	1.E+05
Cryptophyceae						
Cryptomonas sp.*	2.E+03	3240	2.E+08	9960	3.E+09	1.E+09
Chrysophyceae						
Dinobryon sp.*	4.E+02	25	1.E+06	16	1.E+04	2.E+05
Cyanophyceae						
Anabaena sp.*	3.E+05	90	2.E+08	77	2.E+08	1.E+08
Ceratium sp.*	8.E+04		1.E+08		8.E+07	6.E+07
Peridinium sp.*	1.E+04	5	6.E+06	2	3.E+06	2.E+06
Synurophyceae						
Mallomonas *	2.E+03	2	3.E+05	2	3.E+05	2.E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D67. Phytoplankton counts and biovolume, Site D (7/9/2010)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Aulocoseira sp.*	1.36E+03					9.00E+00	2.E+06	2.24E+06
Fragilaria sp.*	1.88E+03	1840	3.43E+08	2280	1.11E+07	2.72E+03	6.E+08	1.50E+09
Stephanodiscus sp.	2.01E+04			5.00	1.04E+07	1.00E+00	3.E+06	2.03E+07
Chlorophyceae								
Closterium sp.*	1.09E+03	3	3.26E+05	1.00	1.13E+05	1.00E+00	1.E+05	9.04E+05
Closterium sp. Large	1.05E+03					2.00E+00	3.E+05	3.82E+05
Coelastrum sp.*	1.25E+04					1	2.E+06	2.29E+06
Characium sp.*	1.23E+03			2.00	2.54E+05			4.06E+05
Oocystis sp.*	1.59E+03					4.00E+00	8.E+05	1.16E+06
Pediastrum sp.*	1.51E+04	1	1.50E+06	1.00	1.56E+06	1.00E+00	2.E+06	7.64E+06
Scenedesmus sp.*	1.89E+02							
Staurastrum sp.*	3.35E+04	2	6.65E+06	4.00	1.39E+07	1.00E+00	4.E+06	3.89E+07
Ankyra sp*	1.01E+02	320	3.20E+06	40	1.04E+04	2.00E+00	3.E+04	5.17E+06
Eudorina sp.*	9.09E+02					1	1.E+05	1.66E+05
Cryptophyceae								
Cryptomonas sp.*	1.61E+03	14120	5.15E+09	6080.00	2.59E+09	1.72E+03	4.E+08	1.30E+10
Cyanophyceae								
Anabaena sp.*	2.76E+05	20	8.54E+07	7.00	6.60E+07	83.00	4.E+08	7.85E+08
Aphanizomenon sp.*	7.21E+03	98	7.03E+07	85.00	6.35E+07	76.00	7.E+07	3.14E+08
Dinophyceae								
Ceratium sp.*	8.31E+04	7	5.78E+07	7.00	6.02E+07			1.89E+08
Peridinium sp.*	1.29E+04	840	1.08E+09	2320.00	3.11E+09	1.56E+03	3.E+09	1.04E+10
Synurophyceae								
Mallomonas *	1.61E+03	10	1.60E+06	6.00	9.99E+05	4.00E+00	8.E+05	5.33E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D68. Phytoplankton counts and biovolume, Site D (7/23/2010)

Class/Genus	biovolume per unit µm³	water depth				depth weighted average biovolume
		at the surface		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae						
Aulocoseira sp.*	1.36E+03	36	4.44E+06	360	5.37E+07	4.53E+07
Cocconeis sp.*	4.93E+03			1	5.39E+05	4.47E+05
Fragilaria sp.*	1.88E+03	18	3.06E+06	165	3.38E+07	2.86E+07
Stephanodiscus sp.	2.01E+04	6.00	1.09E+07	12	2.64E+07	2.38E+07
Chlorophyceae						
Closterium sp.*	1.07E+03	7	6.89E+05	9	1.07E+06	1.00E+06
Coelastrum sp.*	1.25E+04	1	1.13E+06	1.00	1.37E+06	1.33E+06
Characium sp.*	1.23E+03	2	2.22E+05	1.00	1.34E+05	1.49E+05
Pediastrum sp.*	1.51E+04	1	1.36E+06	4.00	6.59E+06	5.70E+06
Scenedesmus sp.*	1.89E+02			4	8.28E+04	6.87E+04
Staurastrum sp.*	3.35E+04	1	3.03E+06	1.00	3.66E+06	3.55E+06
Eudorina sp.*	9.09E+02			10	9.94E+05	8.25E+05
Cryptophyceae						
Cryptomonas sp.*	1.61E+03	4560	1.26E+09	6640	1.47E+09	1.44E+09
Cyanophyceae						
Anabaena sp.***	2.76E+05	126	4.76E+08	43	2.50E+08	2.89E+08
Aphanizomenon sp.***	7.21E+03	600	3.92E+08	440	3.47E+08	3.55E+08
Microcystis sp.*	1.80E+05			12	2.36E+08	1.96E+08
Lyngbya sp.***	2.16E+04	14	2.73E+07	5	1.18E+07	1.44E+07
Gomphosphaeria sp.*	3.51E+04	4	1.27E+07			2.17E+06
Dinophyceae						
Ceratium sp.*	8.31E+04	243	1.83E+09	225.00	2.04E+09	2.01E+09
Peridinium sp.*	2.74E+04	21320	2.50E+10	19565.00	2.77E+10	2.72E+10
Euglenophyceae						
Euglena sp.*	2.10E+03		2.10E+03	40.00	9.17E+06	7.61E+06
Lepocinclis sp.*	1.12E+04			40.00	4.89E+07	4.05E+07

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D69. Phytoplankton counts and biovolume, Site D (8/6/2010)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Aulocoseira sp.*	1.36E+03	17	2.45E+06			30	3.68E+06	4.29E+06
Fragilaria sp.*	1.88E+03	400	7.93E+07	840	1.86E+08	560	9.44E+07	1.82E+08
Navicula sp.*	9.97E+02					1	8.96E+04	8.96E+04
Stephanodiscus sp.	2.01E+04	13	2.76E+07	4	9.52E+06	14	2.53E+07	3.56E+07
Chlorophyceae								
Closterium sp.*	1.07E+03	21	2.42E+06	10	1.29E+06	24	2.36E+06	3.43E+06
Coelastrum sp.*	1.25E+04					2	2.25E+06	2.25E+06
Characium sp.*	1.23E+03	4	5.18E+05	2	2.90E+05	1	1.10E+05	3.45E+05
Pediastrum sp.*	1.51E+04			1	1.78E+06			6.43E+05
Staurastrum sp.*	3.35E+04	4	1.41E+07	1	3.96E+06	1	3.01E+06	7.97E+06
Cryptophyceae								
Cryptomonas sp.*	1.61E+03	3680	1.07E+09	8560	1.01E+09	4200	1.05E+09	1.69E+09
Cyanophyceae								
Anabaena sp.***	2.76E+05	121	2.73E+08	80	1.61E+08	3	5.12E+07	1.78E+08
Aphanizomenon sp.***	7.21E+03	280	2.13E+08	240	2.05E+08	320	2.07E+08	3.35E+08
Microcystis sp.*	1.80E+05	4	7.62E+07	7	1.49E+08			7.29E+07
Lyngbya sp.***	2.16E+04	5	1.14E+07	5	1.28E+07	6	1.16E+07	1.91E+07
Dinophyceae								
Ceratium sp.*	8.31E+04	110	9.66E+08	95	9.34E+08	65	4.85E+08	1.06E+09
Peridinium sp.*	2.74E+04	9282	1.27E+10	7480	1.14E+10	4486	5.23E+09	1.25E+10
Lepocinclis sp.*	1.12E+04					1	1.00E+06	1.00E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D70. Phytoplankton counts and biovolume, Site D (8/20/2010)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Aulocoseira sp.*	1.36E+03	14	2.10E+06	12	1.62E+06	32	4.58E+06	5.59E+06
Cocconeis sp.*	4.93E+03			2	9.75E+05	2	1.04E+06	1.38E+06
Fragilaria sp.*	1.88E+03	480	9.93E+07	520	9.64E+07	373	7.35E+07	1.28E+08
Stephanodiscus sp.	2.01E+04	18	3.99E+07	47	9.34E+07	25	5.28E+07	9.38E+07
Class Chlorophyceae								
Closterium sp.*	1.09E+03	9	1.09E+06	19	2.06E+06	15	1.72E+06	2.67E+06
Closterium sp.	1.05E+03	1	1.15E+05			2	2.20E+05	2.44E+05
Coelastrum sp.*	1.25E+04			6	7.42E+06			2.59E+06
Characium sp.*	1.23E+03	4	5.41E+05	6	7.27E+05	6	7.73E+05	1.14E+06
Oocystis sp.*	1.59E+03			8	1.26E+06	2	3.34E+05	7.72E+05
Pediastrum sp.*	1.51E+04	2	3.32E+06	3	4.47E+06	5	7.91E+06	1.02E+07
Staurastrum sp.*	3.35E+04			1	3.31E+06	2	7.03E+06	8.18E+06
Ankyra sp*	1.01E+02	200	2.22E+06	40	3.98E+05	160	1.69E+06	2.30E+06
Cryptophyceae								
Cryptomonas sp.*	1.61E+03	19080	2.09E+09	25280	2.15E+09	7040	1.54E+09	2.73E+09
Cyanophyceae								
Anabaena sp.*	2.76E+05	3	1.77E+08	2	5.46E+07	6	3.37E+08	3.94E+08
Aphanizomenon sp.*	7.21E+03	280	2.23E+08	120	8.56E+07	360	2.73E+08	3.50E+08
Microcystis sp.*	1.80E+05	6	1.19E+08			4	7.57E+07	1.01E+08
Lyngbya sp.*	2.16E+04	12	2.85E+07	8	1.71E+07	16	3.63E+07	4.82E+07
Gomphosphaeria sp.*	3.51E+04	1	3.87E+06	19	6.60E+07			2.38E+07
Dinophyceae								
Ceratium sp.*	8.31E+04		9.25E+08		6.98E+08		7.42E+08	1.18E+09
Peridinium sp.*	2.74E+04	12455	1.78E+10	11132	1.43E+10	8568	1.17E+10	2.04E+10
Gymnodinium sp.*	1.97E+03			3	5.83E+05			2.03E+05
Euglenophyceae								
Lepocinclis sp.*	1.12E+04					4	4.69E+06	4.69E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D71. Phytoplankton counts and biovolume, Site D (9/3/2010)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Aulocoseira sp.*	1.36E+03			25	3.65E+06	20	2.15E+06	2.12E+06
Cocconeis sp.*	4.93E+03					1	3.89E+05	1.24E+05
Fragilaria sp.*	1.88E+03	1360	3.25E+08	720	1.45E+08	3160	4.67E+08	2.99E+08
Stephanodiscus sp.	2.01E+04	10	2.56E+07	17	3.66E+07	12	1.90E+07	2.79E+07
Class Chlorophyceae								
Closterium sp.*	1.09E+03	12	1.67E+06	15	1.76E+06	25	2.16E+06	1.86E+06
Coelastrum sp.*	1.25E+04	1	1.60E+06					4.59E+05
Characium sp.*	1.23E+03	1	1.56E+05	1	1.31E+05	3	2.90E+05	1.89E+05
Oocystis sp.*	1.59E+03	3	6.08E+05	5	8.51E+05	6	7.51E+05	7.49E+05
Pediastrum sp.*	1.51E+04					1	1.19E+06	3.78E+05
Scenedesmus sp.*	1.89E+02					4	5.97E+04	1.90E+04
Staurastrum sp.*	3.35E+04	7	2.99E+07	7	2.51E+07	8	2.11E+07	2.52E+07
Ankyra sp*	1.01E+02	15	1.92E+05					5.54E+04
Cryptophyceae								
Cryptomonas sp.*	1.61E+03	6160	2.07E+09	3800	1.13E+09	6040	1.11E+09	1.39E+09
Cyanophyceae								
Anabaena sp.*	2.76E+05	1	6.82E+07	6	3.44E+08	9	1.75E+08	2.11E+08
Aphanizomenon sp.*	7.21E+03	16	1.47E+07	8	6.18E+06	25	1.42E+07	1.12E+07
Microcystis sp.*	1.80E+05	6	1.38E+08	1	1.93E+07	9	1.28E+08	8.80E+07
Gomphosphaeria sp.*	3.51E+04	3	1.34E+07	6	2.26E+07	8	2.22E+07	1.98E+07
Dinophyceae								
Ceratium sp.*	8.31E+04		3.71E+08		7.57E+08		3.67E+08	5.22E+08
Peridinium sp.*	2.74E+04	6006	9.92E+09	9567	1.33E+10	10165	1.04E+10	1.14E+10
Gymnodinium sp.*	1.97E+03			2	4.22E+05			1.66E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D72. Phytoplankton counts and biovolume, Site D (9/17/2010)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Aulocoseira sp.*	1.36E+03			11	1.75E+06	5	7.66E+05	9.95E+05
Cocconeis sp.*	4.93E+03					1	5.54E+05	2.28E+05
Cymbella sp.*	9.01E+03	1	9.94E+05			1	1.01E+06	6.15E+05
Fragilaria sp.*	1.88E+03	1200	2.48E+08	3520	7.70E+08	1120	2.36E+08	4.46E+08
Navicula sp.*	9.97E+02	1	1.10E+05			2	2.24E+05	1.14E+05
Stephanodiscus sp.	2.01E+04	6	1.33E+07	8	1.88E+07	3	6.78E+06	1.27E+07
Unkn. diatom	1.10E+04			1	1.28E+06			4.98E+05
Chlorophyceae								
Closterium sp.*	1.07E+03	25	3.02E+06	15	1.91E+06	17	2.09E+06	2.21E+06
Coelastrum sp.*	1.25E+04	3	4.14E+06	1	1.46E+06	1	1.41E+06	1.97E+06
Oocystis sp.*	1.59E+03	5	8.76E+05			1	1.79E+05	2.49E+05
Pediastrum sp.*	1.51E+04	1	1.66E+06			2	3.39E+06	1.72E+06
Staurastrum sp.*	3.35E+04	4	1.48E+07	4	1.56E+07	3	1.13E+07	1.37E+07
Ankyra sp*	1.01E+02	25	2.77E+05	25	2.93E+05	20	2.26E+05	2.62E+05
Quadrigulla sp.*	2.75E+02			12	3.85E+05	4	1.24E+05	2.00E+05
Cryptophyceae								
Cryptomonas sp.*	1.61E+03	4735	1.09E+09	4960	1.79E+09	4000	1.36E+09	1.47E+09
Cyanophyceae								
Anabaena sp.	5.35E+05	9	5.31E+08	8	4.99E+08	5	3.01E+08	4.24E+08
Aphanizomenon sp.*	7.21E+03	3	2.39E+06	5	4.20E+06	3	2.43E+06	3.11E+06
Microcystis sp.*	1.80E+05			2	4.20E+07			1.63E+07
Lyngbya sp.*	2.16E+04	1	2.38E+06	2	5.03E+06	1	2.42E+06	3.43E+06
Gomphosphaeria sp.*	3.51E+04	11	4.26E+07			4	1.58E+07	1.50E+07
Dinophyceae								
Ceratium sp.*	8.31E+04		2.29E+08		1.94E+08		1.40E+08	1.79E+08
Peridinium sp.*	2.74E+04	8283	1.18E+10	8200	1.24E+10	4520	6.57E+09	9.87E+09
Gymnodinium sp.*	1.97E+03					1	2.21E+05	9.09E+04
Euglenophyceae								
Lepocinclis sp.*	1.12E+04					1	1.26E+06	5.16E+05
Synurophyceae								
Mallomonas *	1.61E+03	15	2.66E+06	7	1.31E+06	8	1.45E+06	1.64E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D73. Phytoplankton counts and biovolume, Site D (1/10/2010)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Cocconeis sp.*	4.93E+03	1	6.25E+05			3	1.30E+06	6.23E+05
Fragilaria sp.*	1.88E+03	2440	5.80E+08	2960	5.90E+08	4680	7.74E+08	6.52E+08
Stephanodiscus sp.	2.01E+04	15	3.82E+07	16	3.42E+07	25	4.43E+07	3.88E+07
Unkn. diatom	1.10E+04					1	9.68E+05	3.41E+05
Chlorophyceae								
Closterium sp.*	1.09E+03	6	8.32E+05	15	1.74E+06	9	8.68E+05	1.20E+06
Coelastrum sp.*	1.25E+04	1	1.59E+06			1	1.10E+06	8.03E+05
Characium sp.*	1.23E+03	1	1.55E+05					4.06E+04
Pediastrum sp.*	1.51E+04			1	1.60E+06			6.18E+05
Scenedesmus sp.*	1.89E+02	4	9.59E+04	4	8.04E+04	4	6.67E+04	7.96E+04
Staurastrum sp.*	3.35E+04	1	4.24E+06	1	3.55E+06	2	5.90E+06	4.56E+06
Ankyra sp.*	1.01E+02	40	5.10E+05	80	8.54E+05			4.63E+05
Quadrigulla sp.*	2.75E+02	8	2.79E+05	12	3.50E+05	12	2.91E+05	3.11E+05
Cryptophyceae								
Cryptomonas sp.*	1.61E+03	10402	4.84E+09	11600	4.70E+09	13000	4.58E+09	4.69E+09
Cyanophyceae								
Anabaena sp.*	2.76E+05	2	4.32E+06			3	1.41E+08	5.10E+07
Aphanizomenon sp.*	7.21E+03	4	3.66E+06	1	7.66E+05			1.25E+06
Microcystis sp.*	1.80E+05			1	1.91E+07			7.39E+06
Lyngbya sp.*	2.16E+04	12	3.28E+07	7	1.60E+07	11	2.09E+07	2.21E+07
Gomphosphaeria sp.*	3.51E+04	3	1.34E+07	2	7.46E+06	2	6.19E+06	8.56E+06
Dinophyceae								
Ceratium sp.*	8.31E+04		1.05E+07				7.32E+06	5.33E+06
Peridinium sp.*	1.29E+04	1120	1.84E+09	2080	2.86E+09	1000	1.14E+09	1.98E+09

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

D7.7. Phytoplankton abundance and biovolume, Site D (2010)

Table D74. Phytoplankton counts and biovolume, Site D (6/30/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Asterionella sp.*	1.22E+03	250	3.11E+07	185	1.13E+07	98	1.48E+07	1.78E+07
Cocconeis sp.*	1.29E+04	6	7.90E+06	10	6.47E+06	10	1.60E+07	1.11E+07
Fragilaria sp.*	1.88E+03	5150	9.84E+08	6650	6.24E+08	4000	9.27E+08	8.50E+08
Navicula sp.*	1.07E+03			1	5.34E+04			1.60E+04
Stephanodiscus sp.*	2.18E+04	8	1.77E+07	10	1.09E+07	6	1.61E+07	1.50E+07
Synedra sp.*	1.32E+04	1	1.34E+06	2	1.32E+06			7.32E+05
Chlorophyceae								
Closterium sp.*	1.55E+03	1	1.58E+05	5	3.88E+05	1	1.92E+05	2.42E+05
Pediastrum sp.**	1.08E+04			4	2.16E+06	3	4.00E+06	2.45E+06
Staurastrum sp.*	3.85E+04					3	1.43E+07	6.43E+06
Eudorina sp.*	7.89E+03			1	3.95E+05			1.18E+05
Ankira sp*	3.39E+02	5	1.73E+05					4.32E+04
Cryptophyceae								
Cryptomonas sp.*	1.76E+03	15650	1.14E+09	20650	1.07E+09	5950	1.12E+08	6.54E+08
Chrysophyceae								
Dinobryon sp.*	2.96E+02	38	1.15E+06	56	8.30E+05	35	1.28E+06	1.11E+06
Cyanophyceae								
Anabaena sp.***	1.83E+03	25	4.66E+06	38	3.48E+06			2.21E+06
Aphanizomenon sp.***	3.32E+03	12	4.06E+06	17	2.83E+06	16	6.57E+06	4.82E+06
Gomphosphaeria sp.**	1.53E+04	3	4.68E+06					1.17E+06
Dinophyceae								
Ceratium sp.*	9.24E+04	38	3.57E+08	30	1.39E+08			1.31E+08
Peridinium sp.*	2.55E+04	6	1.56E+07	4	5.10E+06	5	1.57E+07	1.25E+07

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D75. Phytoplankton counts and biovolume, Site D (7/13/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Cocconeis sp.*	1.29E+04	3	3.18E+06	2	2.72E+06	1	1.42E+06	2.30E+06
Fragilaria sp.*	1.88E+03	667	1.03E+08	550	1.08E+08	600	1.24E+08	1.13E+08
Stephanodiscus sp.*	2.18E+04	5	8.94E+06	2	4.58E+06	2	4.78E+06	6.03E+06
Chlorophyceae								
Closterium sp.*	1.55E+03	1	1.27E+05	4	6.52E+05	3	5.11E+05	4.27E+05
Characium sp.*	1.36E+03	6	6.67E+05	2	2.85E+05	2	2.98E+05	4.10E+05
Pediastrum sp.**	1.08E+04	7	6.21E+06	8	9.08E+06	4	4.75E+06	6.29E+06
Staurastrum sp.*	3.85E+04	5	1.58E+07	10	4.05E+07	5	2.12E+07	2.43E+07
Ankira sp*	3.39E+02	6	1.67E+05	1	3.56E+04			6.11E+04
Cryptophyceae								
Cryptomonas sp.*	1.76E+03	6143	1.65E+09	3200	1.14E+09	3950	1.04E+09	1.26E+09
Chrysophyceae								
Dinobryon sp.*	2.96E+02	9	2.19E+05	1	3.11E+04	2	6.51E+04	1.05E+05
Cyanophyceae								
Anabaena sp.***	8.49E+05	97	2.93E+08	2	3.84E+05	14	9.33E+08	5.00E+08
Aphanizomenon sp.***	3.32E+03	18667	5.09E+09	12900	4.51E+09	13900	5.08E+09	4.94E+09
Microcystis sp.**	6.99E+04	3	1.72E+07			2	1.54E+07	1.21E+07
Gomphosphaeria sp.**	1.53E+04					7	1.18E+07	5.15E+06
Dinophyceae								
Ceratium sp.*	9.24E+04	48	3.61E+08					1.13E+08
Peridinium sp.*	3.37E+04	52.61905	1.74E+08	11	3.98E+07	32	1.38E+08	1.25E+08

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D76. Phytoplankton counts and biovolume, Site D (7/20/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Cocconeis sp.*	1.29E+04	6	1.01E+07	4	6.52E+06	2	2.91E+06	4.93E+06
Fragilaria sp.*	1.88E+03	22	5.40E+06	6	1.42E+06	30	6.33E+06	4.72E+06
Stephanodiscus sp.*	2.18E+04					2	4.90E+06	2.78E+06
Chlorophyceae								
Closterium sp.*	1.55E+03			3	5.87E+05	2	3.49E+05	3.77E+05
Coelastrum sp.*	6.73E+03					1	7.57E+05	4.30E+05
Characium sp.*	1.36E+03	2	3.54E+05					4.52E+04
Pediastrum sp.**	1.08E+04	6	8.48E+06	3	4.09E+06	3	3.64E+06	4.40E+06
Eudorina sp.*	7.89E+03	20	2.06E+07	15	1.49E+07	2	1.77E+06	8.18E+06
Ankira sp*	3.39E+02	50	2.22E+06	50	2.14E+06			9.33E+05
Cryptophyceae								
Cryptomonas sp.*	1.76E+03	5700	8.45E+08	5200	7.06E+08	1050	1.46E+08	4.05E+08
Cyanophyceae								
Anabaena sp.***	8.49E+05	77	4.89E+09	94	5.36E+09	31	2.10E+09	3.45E+09
Aphanizomenon sp.***	3.32E+03	27650	1.20E+10	29000	1.22E+10	5750	2.15E+09	6.45E+09
Microcystis sp.**	6.99E+04	12	1.10E+08	2	1.76E+07			1.93E+07
Gomphosphaeria sp**	1.53E+04			1	1.93E+06			5.87E+05
Dinophyceae								
Ceratium sp.*	9.24E+04	7	8.46E+07	4	4.66E+07	1	1.04E+07	3.08E+07
Peridinium sp.*	3.37E+04	1502	5.01E+09	850	2.73E+09	153	4.44E+08	4.93E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D77. Phytoplankton counts and biovolume, Site D (7/27/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Aulacoseira sp.*	1.22E+03	12	1.55E+06					2.52E+05
Cocconeis sp.*	1.29E+04	9	1.23E+07	12	1.62E+07	3	3.75E+06	8.48E+06
Fragilaria sp.*	1.88E+03	47	9.30E+06	84	1.65E+07	18	3.27E+06	7.79E+06
Stephanodiscus sp.*	2.18E+04	2	4.59E+06					7.48E+05
Class Chlorophyceae								
Closterium sp.*	1.55E+03	1	1.64E+05	4	6.50E+05	4	6.01E+05	5.43E+05
Closterium sp.	1.82E+05	5	9.57E+07					1.56E+07
Coelastrum sp.*	6.73E+03	3	2.13E+06	3	2.11E+06	1	6.51E+05	1.28E+06
Oocystis sp.*	1.49E+03					4	5.77E+05	3.29E+05
Pediastrum sp.**	1.08E+04	4	4.56E+06	8	9.05E+06	7	7.32E+06	7.33E+06
Staurastrum sp.*	3.85E+04			1	4.03E+06	1	3.73E+06	3.20E+06
Cryptophyceae								
Cryptomonas sp.*	1.76E+03	100	4.64E+07	265	5.85E+07	450	4.83E+07	5.07E+07
Chrysophyceae								
Dinobryon sp.*	2.96E+02			150	4.65E+06			1.24E+06
Cyanophyceae								
Anabaena sp.***	8.49E+05	86	7.70E+09	46	6.39E+09	5	1.65E+08	3.06E+09
Aphanizomenon sp.***	3.32E+03	27950	9.80E+09	33200	1.16E+10	27150	8.73E+09	9.66E+09
Microcystis sp.**	6.99E+04	15	1.11E+08	14	1.02E+08	16	1.08E+08	1.07E+08
Gomphosphaeria sp.**	1.53E+04	4	6.46E+06	1	1.60E+06			1.48E+06
Dinophyceae								
Ceratium sp.*	9.24E+04	4	3.90E+07	6	5.80E+07	5	4.47E+07	4.73E+07
Peridinium sp.*	3.37E+04	1766	4.78E+09	3516	9.41E+09	2560	6.33E+09	6.90E+09

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D78. Phytoplankton counts and biovolume, Site D (8/3/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Cocconeis sp.*	1.29E+04	9	1.20E+07	5	7.34E+06	5	8.26E+06	8.62E+06
Fragilaria sp.*	1.88E+03	20	3.88E+06	12	2.55E+06			1.39E+06
Navicula sp.*	1.07E+03			1	1.21E+05			3.53E+04
Synedra sp.*	1.32E+04			3	4.49E+06			1.31E+06
Unkn. Diatom*	1.05E+03	45	4.86E+06	56	6.64E+06	16		2.75E+06
Chlorophyceae								
Closterium sp.*	1.55E+03	5	8.03E+05	12	2.11E+06	11	2.18E+06	1.93E+06
Coelastrum sp.*	6.73E+03	1	6.96E+05	16	1.22E+07	8	6.88E+06	7.41E+06
Characium sp.*	1.36E+03	2	2.80E+05					4.67E+04
Pediastrum sp.**	1.08E+04	11	1.23E+07	10	1.23E+07	3	4.14E+06	7.87E+06
Scenedesmus sp.*	8.47E+01			24	2.31E+05	4	4.33E+04	9.08E+04
Staurastrum sp.*	3.85E+04			1	4.37E+06	2	9.85E+06	6.61E+06
Ankira sp*	3.39E+02	50	1.75E+06	2	7.70E+04			3.15E+05
Pandorina sp.*	1.92E+03			10	2.18E+06	1	2.46E+05	7.69E+05
Cryptophyceae								
Cryptomonas sp.*	1.76E+03	3650	1.58E+09	4700	1.58E+09	1578.947	8.39E+08	1.18E+09
Chrysophyceae								
Dinobryon sp.*	2.96E+02			2	6.72E+04	1	3.79E+04	4.01E+04
Cyanophyceae								
Anabaena sp.***	8.49E+05	48	6.84E+09	80	7.13E+09	24	2.82E+09	4.75E+09
Aphanizomenon sp.***	3.32E+03	4150	1.43E+09	3800	1.43E+09	1450	6.16E+08	9.90E+08
Microcystis sp.**	6.99E+04	26	1.88E+08	20	1.59E+08	22	1.97E+08	1.84E+08
Lyngbya sp.***	2.93E+03	7	2.12E+06	6	2.00E+06			9.36E+05
Gomphosphaeria sp**	1.53E+04	3	4.75E+06	11	1.91E+07	9	1.76E+07	1.59E+07
Dinophyceae								
Ceratium sp.*	9.24E+04	67	6.40E+08	21	2.20E+08	4	4.72E+07	1.96E+08
Peridinium sp.*	3.37E+04	6069	1.60E+10	5374	1.56E+10	953.3684	3.12E+09	8.91E+09
Euglenophyceae								
Lepocinclis sp.*	7.56E+03	3	2.35E+06	4	3.43E+06	1	9.66E+05	1.91E+06
Synurophyceae								
Mallomonas sp.*	1.61E+03			4	7.30E+05			2.13E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D79. Phytoplankton counts and biovolume, Site D (8/17/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Aulacoseira sp.*	1.22E+03			18	1.91E+06	29	2.49E+06	1.87E+06
Cocconeis sp.*	1.29E+04			12	1.35E+07	6	5.47E+06	6.73E+06
Fragilaria sp.*	1.88E+03			12	1.96E+06			5.54E+05
Navicula sp.*	1.07E+03			1	9.30E+04			2.63E+04
Unkn. Diatom*	1.05E+03					1	7.36E+04	3.92E+04
Chlorophyceae								
Closterium sp.*	1.55E+03	100	1.76E+07	82	1.11E+07	7	7.65E+05	6.79E+06
Coelastrum sp.*	6.73E+03	25	1.90E+07	17	9.97E+06	25	1.19E+07	1.27E+07
Pediastrum sp.**	1.08E+04	10	1.22E+07	14	1.32E+07	9	6.85E+06	9.63E+06
Scenedesmus sp.*	8.47E+01	12	1.15E+05	48	3.54E+05	1400	8.36E+06	4.57E+06
Staurastrum sp.*	3.85E+04	2	8.72E+06			1	2.72E+06	3.06E+06
Ankira sp*	3.39E+02			1	2.96E+04	4	9.56E+04	5.93E+04
Pandorina sp.*	1.92E+03			45	7.54E+06	2	2.71E+05	2.27E+06
Cryptophyceae								
Cryptomonas sp.*	1.76E+03	8000	2.34E+09	10050	1.82E+09	6550	8.07E+08	1.38E+09
Cyanophyceae								
Anabaena sp.***	1.70E+06			7	1.03E+09	13	1.55E+09	1.12E+09
Aphanizomenon sp.***	3.32E+03	1550	5.83E+08	200	5.79E+07	550	1.29E+08	1.93E+08
Microcystis sp.**	6.99E+04	1	7.91E+06	8	4.87E+07	17	8.37E+07	5.98E+07
Lyngbya sp.***	2.93E+03			21	5.37E+06	35	7.23E+06	5.37E+06
Gomphosphaeria sp.**	1.53E+04	10	1.73E+07	31	4.14E+07	11	1.19E+07	2.12E+07
Dinophyceae								
Ceratium sp.*	9.24E+04	2	2.09E+07	15	1.21E+08	2	1.30E+07	4.49E+07
Peridinium sp.*	3.37E+04	10000	2.89E+10	5639	1.27E+10	6265	1.13E+10	1.50E+10
Euglenophyceae								
Euglena sp.*	2.89E+03			7	1.76E+06	12	2.44E+06	1.80E+06
Lepocinclis sp.*	7.56E+03			22	1.45E+07	20	1.06E+07	9.76E+06
Synurophyceae								
Mallomonas sp.*	1.61E+03			1	1.40E+05	1	1.13E+05	9.99E+04

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D80. Phytoplankton counts and biovolume, Site D (8/30/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Asterionella sp.*	1.22E+03	36	4.78E+06					9.35E+05
Aulacoseira sp.*	1.22E+03			35	4.46E+06	45	5.11E+06	3.97E+06
Cocconeis sp.*	1.29E+04	33	4.63E+07			4	4.81E+06	1.19E+07
Chlorophyceae								
Closterium sp.*	1.55E+03	14	2.36E+06	13	2.10E+06	7	1.01E+06	1.50E+06
Coelastrum sp.*	6.73E+03	12	8.77E+06	9	6.32E+06	21	1.31E+07	1.09E+07
Characium sp.*	1.36E+03					4	5.04E+05	3.01E+05
Pediastrum sp.**	1.08E+04	1	1.17E+06	3	3.38E+06			9.28E+05
Scenedesmus sp.*	8.47E+01	12	1.10E+05			40	3.15E+05	2.10E+05
Ankira sp*	3.39E+02	15	5.52E+05			15	4.73E+05	3.91E+05
Pandorina sp*	1.92E+03	35	7.30E+06	45	9.02E+06	67	1.20E+07	1.05E+07
Cryptophyceae								
Cryptomonas sp.*	1.76E+03	2450	7.30E+08	3050	1.27E+09	3400	1.10E+09	1.06E+09
Chrysophyceae								
Dinobryon sp.*	2.96E+02	14	4.50E+05	12	3.71E+05	8	2.20E+05	2.96E+05
Cyanophyceae								
Anabaena sp.***	8.49E+05	37	6.81E+09	11	1.95E+09	31	3.63E+09	3.90E+09
Aphanizomenon sp.***	3.32E+03	450	1.62E+08	950	3.29E+08	400	1.24E+08	1.74E+08
Microcystis sp.**	6.99E+04	17	1.29E+08			19	1.23E+08	9.91E+07
Oscillatoria sp. ***	1.23E+04					2	2.28E+06	1.37E+06
Lyngbya sp.***	2.93E+03	14	4.46E+06	15	4.59E+06	8	2.18E+06	3.12E+06
Gomphosphaeria sp.**	1.53E+04	24	3.99E+07	7	1.12E+07	34	4.84E+07	3.91E+07
Dinophyceae								
Ceratium sp.*	9.24E+04	14	1.40E+08	14	1.35E+08	32	2.75E+08	2.20E+08
Peridinium sp.*	3.37E+04	6125	1.70E+10	6235	1.66E+10	6220	1.48E+10	1.56E+10
Euglenophyceae								
Euglena sp.*	2.89E+03	4	1.25E+06			50	1.34E+07	8.28E+06
Lepocinclis sp.*	7.56E+03					50	3.51E+07	2.10E+07
Synurophyceae								
Mallomonas sp.*	1.61E+03	6	1.05E+06					2.05E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D81. Phytoplankton counts and biovolume, Site D (9/20/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Aulacoseira sp.*	1.22E+03	33	3.99E+06	16	2.22E+06	18	2.33E+06	2.75E+06
Cocconeis sp.*	1.29E+04	1	1.28E+06	2	2.94E+06	14	1.92E+07	7.90E+06
Cymbella sp.*	1.42E+04					1	1.51E+06	5.03E+05
Fragilaria sp.*	1.88E+03	5	9.29E+05	24	5.12E+06			2.25E+06
Navicula sp.*	1.07E+03					2	2.27E+05	7.55E+04
Unkn. Diatom*	1.05E+03					1	1.11E+05	3.70E+04
Chlorophyceae								
Closterium sp.*	9.16E+04	16	2.03E+07	10	1.76E+06	15	2.47E+06	7.14E+06
Coelastrum sp.*	6.73E+03	25	1.67E+07	18	1.38E+07	16	1.14E+07	1.38E+07
Characium sp.*	1.36E+03			3	4.62E+05	6	8.63E+05	4.67E+05
Oocystis sp.*	1.49E+03			6	1.02E+06			3.95E+05
Pediastrum sp.**	1.08E+04	2	2.14E+06			3	3.44E+06	1.74E+06
Scenedesmus sp.*	8.47E+01					4	3.60E+04	1.20E+04
Ankira sp*	3.39E+02					150	5.40E+06	1.80E+06
Cryptophyceae								
Cryptomonas sp.*	2.59E+03	4700	1.83E+09	4000	1.71E+09	1650	7.13E+08	1.41E+09
Chrysophyceae								
Dinobryon sp.*	2.96E+02	12	3.52E+05	32	1.08E+06	4	1.26E+05	5.59E+05
Cyanophyceae								
Anabaena sp.***	8.49E+05	14	6.73E+08	8	1.16E+09	17	2.34E+09	1.42E+09
Aphanizomenon sp.***	3.32E+03	50	1.65E+07	3200	1.21E+09	3050	1.08E+09	8.34E+08
Oscillatoria sp. ***	1.23E+04					1	1.30E+06	4.35E+05
Lyngbya sp.***	2.93E+03			1	3.33E+05			1.30E+05
Gomphosphaeria sp**	1.53E+04	4	6.07E+06	6	1.04E+07	13	2.11E+07	1.28E+07
Dinophyceae								
Ceratium sp.*	3.37E+04	5700	1.44E+10	4802	1.39E+10	88	2.43E+08	9.49E+09
Euglenophyceae								
Euglena sp.*	2.89E+03					1	3.07E+05	1.02E+05
Synurophyceae								
Mallomonas sp.*	1.61E+03	2	3.18E+05	3	5.48E+05	1		3.02E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D82. Phytoplankton counts and biovolume, Site D (10/4/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Aulacoseira sp.*	1.22E+03					38	4.39E+06	6.68E+05
Cocconeis sp.*	1.29E+04	2	2.19E+06	1	1.08E+06	8	9.79E+06	2.95E+06
Fragilaria sp.*	1.88E+03	16	2.54E+06			34	6.04E+06	2.16E+06
Navicula sp.*	1.07E+03	1	9.05E+04					4.43E+04
Stephanodiscus sp.*	2.18E+04	1	1.85E+06					9.03E+05
Synedra sp.*	1.32E+04	1	1.12E+06	2	2.20E+06	3	3.75E+06	1.91E+06
Unkn. diatom*	1.05E+03	3	2.66E+05			2	1.98E+05	1.60E+05
Cyclotella sp.*	8.56E+02							
Chlorophyceae								
Closterium sp.*	1.55E+03	6	7.89E+05	6	7.76E+05	2	2.94E+05	7.09E+05
Coelastrum sp.*	6.73E+03	8	4.57E+06			6	3.82E+06	2.81E+06
Characium sp.*	1.36E+03					2	2.56E+05	3.90E+04
Oocystis sp.*	1.49E+03	2	2.53E+05			3	4.23E+05	1.88E+05
Pediastrum sp.**	1.08E+04	10	9.16E+06					4.48E+06
Scenedesmus sp.*	8.47E+01					4	3.21E+04	4.88E+03
Quadrigulla sp.*	2.75E+02	4	9.32E+04					4.56E+04
Pandorina sp.*	1.92E+03	1	1.63E+05					7.97E+04
Cryptophyceae								
Cryptomonas sp.*	1.76E+03	1750	5.34E+08	1150	4.21E+08	1252	5.20E+08	4.91E+08
Cyanophyceae								
Aphanizomenon sp.***	3.32E+03	100	2.82E+07	100	2.77E+07	150	4.72E+07	3.09E+07
Gomphosphaeria sp.**	1.53E+04	2	2.60E+06	1	1.28E+06			1.73E+06
Dinophyceae								
Peridinium sp.*	3.37E+04	3	9.28E+06	1	2.12E+06	6	1.60E+07	7.74E+06

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D83. Phytoplankton counts and biovolume, Site D (10/18/2011)

Class/Genus	biovolume per unit µm³	water depth				depth weighted average biovolume
		at the surface		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae						
Aulacoseira sp.*	1.22E+03	8	5.60E+05			2.29E+05
Cocconeis sp.*	1.29E+04	10	7.41E+06	6	9.13E+06	8.42E+06
Cymbella sp.*	1.42E+04	1	8.15E+05			3.34E+05
Fragilaria sp.*	1.88E+03	152	1.63E+07	126	2.78E+07	2.31E+07
Navicula sp.*	1.07E+03	1	6.12E+04	3	3.77E+05	2.47E+05
Stephanodiscus sp.*	2.18E+04	6	7.49E+06	2	5.12E+06	6.09E+06
Synedra sp.*	1.32E+04	7	5.30E+06	3	4.66E+06	4.92E+06
Cyclotella sp.*	8.56E+02	30	1.47E+06	15	1.51E+06	1.49E+06
Class Chlorophyceae						
Closterium sp.*	1.55E+03	9	8.01E+05	11	2.01E+06	1.51E+06
Coelastrum sp.*	6.73E+03			1	7.92E+05	4.67E+05
Cosmarium sp.*	2.37E+04	1	1.36E+06			5.56E+05
Pediastrum sp.**	1.08E+04	1	6.20E+05	1	1.27E+06	1.00E+06
Scenedesmus sp.*	8.47E+01	8	3.89E+04	4	3.99E+04	3.95E+04
Quadrigulla sp.*	2.75E+02	20	3.15E+05	24	7.76E+05	5.87E+05
Ankira sp*	3.39E+02	400	7.78E+06	200	7.98E+06	7.90E+06
Cryptophyceae						
Cryptomonas sp.*	2.59E+03	2750	6.83E+08	3700	1.70E+09	1.28E+09
Cyanophyceae						
Anabaena sp.***	1.83E+03	2	2.10E+05			8.60E+04
Aphanizomenon sp.***	3.32E+03	150	2.86E+07	200	7.82E+07	5.79E+07
Gomphosphaeria sp.**	1.53E+04	1	8.78E+05	3	5.40E+06	3.55E+06
Synurophyceae						
Mallomonas sp.*	1.61E+03	2	1.84E+05	1	1.89E+05	1.87E+05

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

Table D84. Phytoplankton counts and biovolume, Site D (11/8/2011)

Class/Genus	biovolume per unit µm³	water depth						depth weighted average biovolume
		at the surface		at the Secchi depth		at the 2 × Secchi depth		
		units/ml	µm³/L	units/ml	µm³/L	units/ml	µm³/L	µm³/L
Bacillariophyceae								
Asterionella sp.*	1.22E+03	40	3.94E+06	76	9.49E+06	40	4.11E+06	5.99E+06
Aulacoseira sp.*	1.22E+03			3	3.74E+05			1.34E+05
Cocconeis sp.*	1.29E+04	3	3.12E+06	3	3.96E+06			2.24E+06
Fragilaria sp.*	1.88E+03	600	9.06E+07	1300	2.49E+08	800	1.26E+08	1.61E+08
Navicula sp.*	1.07E+03	50	4.29E+06	50	5.45E+06			3.07E+06
Stephanodiscus sp.*	2.18E+04	16	2.80E+07	13	2.89E+07	8	1.46E+07	2.33E+07
Synedra sp.*	1.32E+04	16	1.70E+07	17	2.29E+07	4	4.43E+06	1.43E+07
Unkn. diatom*	1.05E+03	4	3.36E+05	9	9.60E+05			4.32E+05
Chlorophyceae								
Closterium sp.*	1.55E+03	1	1.25E+05			2	2.61E+05	1.32E+05
Coelastrum sp.*	6.73E+03	3	1.62E+06	1	6.87E+05	1	5.65E+05	8.85E+05
Characium sp.*	1.36E+03					2	2.28E+05	8.66E+04
Pediastrum sp.**	1.08E+04	2	1.74E+06					4.54E+05
Quadrigulla sp.*	2.75E+02			4	1.12E+05			4.03E+04
Ankira sp*	3.39E+02	600	1.64E+07	600	2.08E+07	150	4.27E+06	1.34E+07
Cryptophyceae								
Cryptomonas sp.*	2.59E+03	20950	5.43E+09	15450	4.87E+09	17650	5.94E+09	5.42E+09
Cyanophyceae								
Aphanizomenon sp.***	3.32E+03	150	4.01E+07	150	5.09E+07	21	5.86E+06	3.10E+07

Note: enumeration and biovolume determination are based on a *cell unit, **colony unit and ***filament unit

APPENDIX E: STATISTICAL ANALISIS

E1. Statistics 2010. Onsite Measurements and Nutrients

E1.1. Statistics for water temperature, 2011

Table E1. ANOVA Statistics for water temperature depth distribution, Site A (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	5.81	0.58	0.04	1.0000
Error	76	1246.62	16.41		
Corrected Total	86	1252.43			

Table E2. ANOVA Statistics for water temperature depth distribution, Site B (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	22.22	2.47	0.18	0.9956
Error	62	854.14	13.78		
Corrected Total	71	876.36			

Table E3. ANOVA Statistics for water temperature depth distribution, Site C (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	5.91	1.18	0.11	0.9902
Error	38	420.60	11.07		
Corrected Total	43	426.50			

Table E4. ANOVA Statistics for water temperature depth distribution, Site D (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	13.37	2.23	0.20	0.9745
Error	43	475.76	11.06		
Corrected Total	49	489.14			

E1.2. Statistics for conductivity, 2011

Table E5. ANOVA Statistics for conductivity depth distribution, Site A (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	720.78	80.09	0.03	1.0000
Error	73	200327.92	2744.22		
Corrected Total	82	201048.70			

Table E6. ANOVA Statistics for conductivity depth distribution, Site B (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	7961.41	884.61	0.31	0.9675
Error	61	171883.75	2817.77		
Corrected Total	70	179845.15			

Table E7. ANOVA Statistics for conductivity depth distribution, Site C (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	6060.98	1212.20	0.59	0.7098
Error	38	78483.65	2065.36		
Corrected Total	43	84544.64			

Table E8. ANOVA Statistics for conductivity depth distribution, Site D (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	3081.51	513.59	0.23	0.9663
Error	43	97966.98	2278.31		
Corrected Total	49	101048.48			

E1.3. Statistics for DO, 2010

Table E9. ANOVA Statistics for DO depth distribution, Site A (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	126.46	12.65	4.29	<.0001
Error	74	217.89	2.94		
Corrected Total	84	344.35			

Table E10. Tukey's (HSD) test, p-values for multiple comparisons of DO between sampling depths, Site A (2011)

depths(m)	0.5	1	2	3	4	5	6	7	8	9
0.5		0.99	0.81	0.35	0.12	0.02	0.01	0.00	0.00	0.03
1	0.99		0.82	0.35	0.13	0.02	0.01	0.00	0.00	0.03
2	0.81	0.82		0.48	0.18	0.04	0.01	0.01	0.00	0.05
3	0.35	0.35	0.48		0.52	0.14	0.05	0.03	0.02	0.12
4	0.12	0.13	0.18	0.52		0.39	0.17	0.10	0.06	0.26
5	0.02	0.02	0.04	0.14	0.39		0.58	0.40	0.27	0.59
6	0.01	0.01	0.01	0.05	0.17	0.58		0.77	0.57	0.88
7	0.00	0.00	0.01	0.03	0.10	0.40	0.77		0.77	0.95
8	0.00	0.00	0.00	0.02	0.06	0.27	0.57	0.77		0.79
9	0.03	0.03	0.05	0.12	0.26	0.59	0.88	0.95	0.79	

Table E11. ANOVA Statistics for DO depth distribution, Site B (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	99.55	11.06	2.18	0.0352
Error	62	314.06	5.06		
Corrected Total	71	413.61			

Table E12. Tukey's (HSD) test, p-values for multiple comparisons of DO between sampling depths, Site B (2010)

depths(m)	0.5	1	2	3	4	5	6	7	8	9
0.5		0.7501	0.6038	0.4448	0.2519	0.0767	0.0041	0.0131	0.1378	0.0516
1	0.7501		0.8408	0.6549	0.4061	0.1416	0.0092	0.0226	0.1921	0.0693
2	0.6038	0.8408		0.8054	0.5279	0.2010	0.0149	0.0315	0.2338	0.0829
3	0.4448	0.6549	0.8054		0.6997	0.2970	0.0260	0.0463	0.2935	0.1025
4	0.2519	0.4061	0.5279	0.6997		0.5025	0.0584	0.0817	0.4065	0.1408
5	0.0767	0.1416	0.2010	0.2970	0.5025		0.2085	0.2044	0.6675	0.2384
6	0.0041	0.0092	0.0149	0.0260	0.0584	0.2085		0.7569	0.7067	0.5675
7	0.0131	0.0226	0.0315	0.0463	0.0817	0.2044	0.7569		0.5727	0.7303
8	0.1378	0.1921	0.2338	0.2935	0.4065	0.6675	0.7067	0.5727		0.4566
9	0.0516	0.0693	0.0829	0.1025	0.1408	0.2384	0.5675	0.7303	0.4566	

Table E13. ANOVA Statistics for DO depth distribution, Site C (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	52.01	10.40	3.43	0.0118
Error	38	115.27	3.03		
Corrected Total	43	167.29			

Table E14. Tukey's (HSD) test, p-values for multiple comparisons of DO between sampling depths, Site C (2010)

depths(m)	0.5	1	2	3	4	5
0.5		0.8360	0.3090	0.1127	0.0095	0.0037
1	0.8360		0.4158	0.1650	0.0155	0.0047
2	0.3090	0.4158		0.5569	0.0855	0.0121
3	0.1127	0.1650	0.5569		0.2333	0.0229
4	0.0095	0.0155	0.0855	0.2333		0.0851
5	0.0037	0.0047	0.0121	0.0229	0.0851	

Table E15. ANOVA Statistics for DO depth distribution, Site D (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	25.65	4.27	1.09	0.3870
Error	41	161.44	3.94		
Corrected Total	47	187.09			

E1.4. Statistics for nitrogen, 2010

Table E16. ANOVA Statistics for TDIN depth distribution, Site B (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.001	0.01	0.08	0.9680
Error	35	0.12	0.01		
Corrected Total	38	0.12			

Table E17. ANOVA Statistics for TN depth distribution, Site B (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.48	0.16	0.51	0.6792
Error	31	9.76	0.32		
Corrected Total	34	10.24			

E1.5. Statistics for phosphorus, 2010

Table E18. ANOVA Statistics for SRP depth distribution, Site B (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.48	0.16	0.51	0.6792
Error	31	9.76	0.32		
Corrected Total	34	10.24			

Table E19. ANOVA Statistics for TP depth distribution, Site B (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.01	0.01	0.04	0.9901
Error	35	0.11	0.01		
Corrected Total	38	0.11			

E2. Statistics 2011. Onsite Measurements and Nutrients

E2.1. Statistics for water temperature, 2011

Table E20. ANOVA Statistics for water temperature depth distribution, Site A (2011).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	67.36	7.48	5.97	<.0001
Error	35	43.91	1.25		
Corrected Total	44	111.27			

Table E21. Tukey's (HSD) test, p-values for multiple comparisons of water temperature between sampling depths< Site A (2011)

depths(m)	0.5	1	2	3	4	5	6	7	8	9
0.5		0.8031	0.1858	0.0366	0.0059	0.0008	0.0002	<.0001	<.0001	0.0083
1	0.8031		0.2796	0.0627	0.0112	0.0016	0.0004	0.0002	<.0001	0.0119
2	0.1858	0.2796		0.4153	0.1229	0.0263	0.0076	0.0035	0.0016	0.0511
3	0.0366	0.0627	0.4153		0.4543	0.1435	0.0525	0.0269	0.0120	0.1317
4	0.0059	0.0112	0.1229	0.4543		0.4644	0.2193	0.1295	0.0608	0.2759
5	0.0008	0.0016	0.0263	0.1435	0.4644		0.6126	0.4217	0.2233	0.5012
6	0.0002	0.0004	0.0076	0.0525	0.2193	0.6126		0.7644	0.4536	0.7028
7	<.0001	0.0002	0.0035	0.0269	0.1295	0.4217	0.7644		0.6391	0.8347
8	<.0001	<.0001	0.0016	0.0120	0.0608	0.2233	0.4536	0.6391		0.9384
9	0.0083	0.0119	0.0511	0.1317	0.2759	0.5012	0.7028	0.8347	0.9384	

Table E22. ANOVA Statistics for water temperature depth distribution, Site B (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	55.07	7.87	4.45	0.0020
Error	28	49.48	1.77		
Corrected Total	35	104.56			

Table E23. Tukey's (HSD) test, p-values for multiple comparisons of water temperature between sampling depths, Site B (2011)

depths(m)	0.5	1	2	3	4	5	6	7
0.5		0.9474	0.2915	0.0552	0.0148	0.0032	0.0014	0.0017
1	0.9474		0.3218	0.0633	0.0173	0.0038	0.0016	0.0020
2	0.2915	0.3218		0.3627	0.1391	0.0403	0.0168	0.0131
3	0.0552	0.0633	0.3627		0.5553	0.2308	0.1058	0.0614
4	0.0148	0.0173	0.1391	0.5553		0.5351	0.2771	0.1454
5	0.0032	0.0038	0.0403	0.2308	0.5351		0.6096	0.3150
6	0.0014	0.0016	0.0168	0.1058	0.2771	0.6096		0.5609
7	0.0017	0.0020	0.0131	0.0614	0.1454	0.3150	0.5609	

Table E24. ANOVA Statistics for water temperature depth distribution, Site C (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	16.21	4.05	2.30	0.0946
Error	20	35.28	1.76		
Corrected Total	24	51.49			

Table E25. ANOVA Statistics for water temperature depth distribution, Site D (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	24.13	4.83	1.99	0.1221
Error	21	50.95	2.43		
Corrected Total	26	75.08			

E2.2. Statistics for conductivity, 2011

Table E26. ANOVA Statistics for conductivity depth distribution, Site A (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	79378.74	8819.86	6.84	<.0001
Error	34	43837.15	1289.33		
Corrected Total	43	123215.89			

Table E27. Tukey's (HSD) test, p-values for multiple comparisons of conductivity between sampling depths, Site A (2011)

depths(m)	0.5	1	2	3	4	5	6	7	8	9
0.5		0.9165	0.6625	0.4805	0.2507	0.0084	0.0007	0.0002	<.0001	0.0867
1	0.9165		0.7399	0.5474	0.2926	0.0109	0.0009	0.0002	<.0001	0.0976
2	0.6625	0.7399		0.7865	0.4563	0.0241	0.0023	0.0005	<.0001	0.1402
3	0.4805	0.5474	0.7865		0.6230	0.0444	0.0048	0.0012	<.0001	0.1851
4	0.2507	0.2926	0.4563	0.6230		0.1503	0.0246	0.0074	0.0006	0.3114
5	0.0084	0.0109	0.0241	0.0444	0.1503		0.3571	0.1529	0.0164	0.8836
6	0.0007	0.0009	0.0023	0.0048	0.0246	0.3571		0.6006	0.1094	0.6979
7	0.0002	0.0002	0.0005	0.0012	0.0074	0.1529	0.6006		0.2599	0.4908
8	<.0001	<.0001	<.0001	<.0001	0.0006	0.0164	0.1094	0.2599		0.1797
9	0.0867	0.0976	0.1402	0.1851	0.3114	0.8836	0.6979	0.4908	0.1797	

Table E28. ANOVA Statistics for conductivity depth distributions, Site B (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	36827.50	5261.07	5.72	0.0004
Error	28	25756.50	919.87		
Corrected Total	35	62584.00			

Table E29. Tukey's (HSD) test, p-values for multiple comparisons of conductivity between sampling depths, Site B (2011)

depths(m)	0.5	1	2	3	4	5	6	7
0.5		0.9588	0.7256	0.4288	0.2031	0.0030	0.0006	0.0005
1	0.9588		0.7646	0.4591	0.2212	0.0034	0.0007	0.0006
2	0.7256	0.7646		0.6574	0.3508	0.0072	0.0015	0.0011
3	0.4288	0.4591	0.6574		0.6207	0.0208	0.0043	0.0027
4	0.2031	0.2212	0.3508	0.6207		0.0613	0.0136	0.0068
5	0.0030	0.0034	0.0072	0.0208	0.0613		0.4326	0.1592
6	0.0006	0.0007	0.0015	0.0043	0.0136	0.4326		0.4417
7	0.0005	0.0006	0.0011	0.0027	0.0068	0.1592	0.4417	

Table E30. ANOVA Statistics for conductivity depth distribution, Site C (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	1199.84	299.96	3.87	0.0173
Error	20	1549.60	77.48		
Corrected Total	24	2749.44			

Table E31. Tukey's (HSD) test, p-values for multiple comparisons of conductivity between sampling depths, Site C (2011)

depts (m)	0.5	1	2	3	4
0.5		0.5483	0.2361	0.1662	0.0015
1	0.5483		0.5483	0.4184	0.0063
2	0.2361	0.5483		0.8315	0.0240
3	0.1662	0.4184	0.8315		0.0376
4	0.0015	0.0063	0.0240	0.0376	

Table E32. ANOVA Statistics for conductivity depth distribution, Site D (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	128623.04	25724.61	61.61	<.0001
Error	21	8767.70	417.51		
Corrected Total	26	137390.74			

Table E33. Tukey's (HSD) test, p-values for multiple comparisons of conductivity between sampling depths, Site D (2011)

depts (m)	0.5	1	2	3	4	5
0.5		1.0000	0.6256	0.3959	0.0285	<.0001
1	1.0000		0.6256	0.3959	0.0285	<.0001
2	0.6256	0.6256		0.7140	0.0774	<.0001
3	0.3959	0.3959	0.7140		0.1522	<.0001
4	0.0285	0.0285	0.0774	0.1522		<.0001

E2.3. Statistics for DO, 2011

Table E34. ANOVA Statistics for DO depth distribution, Site A (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	294.22	32.69	14.42	<.0001
Error	35	79.34	2.27		
Corrected Total	44	373.56			

Table E35 Tukey's (HSD) test, p-values for multiple comparisons of DO between sampling depths, Site A (2011)

depth(m)	0.5	1	2	3	4	5	6	7	8	9
0.5		0.2999	0.0196	0.0021	<.0001	<.0001	<.0001	<.0001	<.0001	0.002
1	0.2999		0.1719	0.0292	<.0001	<.0001	<.0001	<.0001	<.0001	0.009
2	0.0196	0.1719		0.3849	0.0017	0.0001	0.0001	<.0001	<.0001	0.0076
3	0.0021	0.0292	0.3849		0.0167	0.0016	0.0014	0.0005	0.0007	0.0261
4	<.0001	<.0001	0.0017	0.0167		0.3661	0.3511	0.1842	0.1851	0.3892
5	<.0001	<.0001	0.0001	0.0016	0.3661		0.9767	0.6634	0.6282	0.7335
6	<.0001	<.0001	0.0001	0.0014	0.3511	0.9767		0.6846	0.6477	0.7462
7	<.0001	<.0001	<.0001	0.0005	0.1842	0.6634	0.6846		0.9408	0.9290
8	<.0001	<.0001	<.0001	0.0007	0.1851	0.6282	0.6477	0.9408		0.9659
9	0.0002	0.0009	0.0076	0.0261	0.3892	0.7335	0.7462	0.9290	0.9659	

Table E36. ANOVA Statistics for DO depth distribution, Site B (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	224.86	32.12	13.20	<.0001
Error	26	63.26	2.40		
Corrected Total	33	288.12			

Table E37. Tukey's (HSD) test, p-values for multiple comparisons of DO between sampling depths, Site B (2011)

depth(m)	0.5	1	2	3	4	5	6	7	8
0.5		0.7742	0.0500	0.0026	<.0001	<.0001	<.0001	0.0003	
1	0.7742		0.0892	0.0053	<.0001	<.0001	<.0001	0.0005	0.7742
2	0.0500	0.0892		0.2121	0.0058	0.0002	0.0002	0.0069	0.0500
3	0.0026	0.0053	0.2121		0.0964	0.0042	0.0031	0.0372	0.0026
4	<.0001	<.0001	0.0058	0.0964		0.1701	0.0899	0.2411	<.0001
5	<.0001	<.0001	0.0002	0.0042	0.1701		0.5941	0.7033	<.0001
6	<.0001	<.0001	0.0002	0.0031	0.0899	0.5941		0.9810	<.0001
7	0.0003	0.0005	0.0069	0.0372	0.2411	0.7033	0.9810		0.0003
8		0.7742	0.0500	0.0026	<.0001	<.0001	<.0001	0.0003	

Table E38. ANOVA Statistics for DO depth distribution, Site C (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	18.77	4.69	0.90	0.4720
Error	49	255.87	5.22		
Corrected Total	53	274.64			

Table E39. ANOVA Statistics for DO depth distributions, Site D (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	10.82	2.70	0.66	0.6302
Error	20	82.61	4.13		
Corrected Total	24	93.43			

E2.4. Statistics for nitrogen, 2011

Table E40. ANOVA Statistics for TDIN depth distribution, Site A (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1.28	0.43	6.92	0.0038
Error	15	0.92	0.06		
Corrected Total	18	2.21			

Table E41. Tukey's (HSD) test, p-values for multiple comparisons of TDIN between sampling depths, Site A (2011)

depth(m)	0.5B	1.5B	SD	T
0.5B		0.9617	0.0044	0.0046
1.5B	0.9617		0.0073	0.0075
SD	0.0044	0.0073		0.9858
T	0.0046	0.0075	0.9858	

Table E42. ANOVA Statistics for TDIN depth distribution, Site B (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.92	0.31	7.44	0.0038
Error	13	0.54	0.04		
Corrected Total	16	1.45			

Table E43. Tukey's (HSD) test, p-values for multiple comparisons of TDIN between sampling depths, Site B (2011)

depth(m)	0.5B	1.5B	SD	T
0.5B		0.1018	0.0012	0.0015
1.5B	0.1018		0.0712	0.0883
SD	0.0012	0.0712		0.8901
T	0.0015	0.0883	0.8901	

Table E44. ANOVA Statistics for TN depth distribution, Site A (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	3.35	1.12	0.98	0.4303
Error	15	17.16	1.14		
Corrected Total	18	20.51			

Table E45. ANOVA Statistics for TN depth distribution, Site B (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1.41	0.47	0.61	0.6192
Error	13	9.92	0.76		
Corrected Total	16	11.32			

E2.5. Statistics for phosphorus, 2011

Table E46. ANOVA Statistics for SRP depth distribution, Site A (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.32	0.11	18.36	<.0001
Error	13	0.07	0.01		
Corrected Total	16	0.40			

Table E47. Tukey's (HSD) post hoc test, p-values for multiple comparisons of SRP between sampling depths, Site A (2011)

depth(m)	0.5B	1.5B	SD	T
0.5B		0.4187	0.0001	0.0008
1.5B	0.4187		<.0001	0.0003
SD	0.0001	<.0001		0.2513
T	0.0008	0.0003	0.2513	

Table E48. ANOVA Statistics for SRP depth distribution, Site B (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.16	0.05	12.05	0.0005
Error	13	0.06	0.01		
Corrected Total	16	0.22			

Table E49. Tukey's (HSD) test, p-values for multiple comparisons of SRP between sampling depths, Site B (2011)

depth(m)	0.5B	1.5B	SD	T
0.5B		0.1217	0.0001	0.0004
1.5B	0.1217		0.0069	0.0244
SD	0.0001	0.0069		0.4575
T	0.0004	0.0244	0.4575	

Table E50. ANOVA Statistics for TP depth distribution, Site A (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.33	0.12	8.91	0.0012
Error	15	0.18	0.01		
Corrected Total	18	0.52			

Table E51. Tukey's (HSD) test, p-values for multiple comparisons of TP between sampling depths, Site B (2011)

depth(m)	0.5B	1.5B	SD	T
0.5B		0.7778	0.0026	0.0025
1.5B	0.7778		0.0022	0.0021
SD	0.0026	0.0022		0.9828
T	0.0025	0.0021	0.9828	

Table E52. ANOVA Statistics for TP depth distribution, Site B (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.18	0.06	7.30	0.0041
Error	13	0.11	0.01		
Corrected Total	16	0.29			

Table E53. Tukey's (HSD) test, p-values for multiple comparisons of TP between sampling depths, Site B (2011)

depth(m)	0.5B	1.5B	SD	T
0.5B		0.4400	0.0204	0.0059
1.5B	0.4400		0.0062	0.0020
SD	0.0204	0.0062		0.5066
T	0.0059	0.0020	0.5066	

E3. Statistics for Phytoplankton

E3.1. Statistics for Chl-*a,* 2010

Table E54. ANOVA Statistics for Chl-*a* depth distribution, Site A (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	613.77	204.58	0.50	0.6825
Error	36	14635.42	406.53		
Corrected Total	39	15249.18			

Table E55. ANOVA Statistics for Chl-*a* depth distribution, Site B (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	676.19	225.39	0.37	0.7785
Error	31	19123.60	616.89		
Corrected Total	34	19799.80			

Table E56. ANOVA Statistics for Chl-*a* depth distribution, Site C (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	717.25061	358.63	0.52	0.6010
Error	23	15845.11293	688.92		
Corrected Total	25	16562.36353			

Table E57. ANOVA Statistics for Chl-*a* depth distribution at Site D (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2535.01	1267.51	0.69	0.5128
Error	22	40503.59	1841.07		
Corrected Total	24	43038.61			

E3.2. Statistics for Chl-*a,* 2011

Table E58. ANOVA Statistics for Chl-*a* depth distribution, Site A (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	9992.65	2498.16	8.37	0.0008
Error	16	4774.16	298.38		
Corrected Total	20	14766.81			

Table E59. Tukey's (HSD) test, p-values for multiple comparisons of Chl-*a* between sampling depths, Site A (2011)

depth(m)	0.5B	1.5B	S	SD	T
0.5B		0.2001	0.0017	0.0008	0.2764
1.5B	0.2001		0.0089	0.0036	0.7533
S	0.0017	0.0089		0.6511	0.0030
SD	0.0008	0.0036	0.6511		0.0011
T	0.2764	0.7533	0.0030	0.0011	

Table E60. ANOVA Statistics for Chl-*a* depth distribution, Site B (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	4587.95	1146.99	3.42	0.0379
Error	14	4699.56	335.68		
Corrected Total	18	9287.52			

Table E61. Tukey's (HSD) test, p-values for multiple comparisons of Chl-*a* between sampling depths, Site B (2011)

depth(m)	0.5B	1.5B	S	SD	T
0.5B		0.6267	0.0301	0.0192	0.4272
1.5B	0.6267		0.0502	0.0303	0.7441
S	0.0301	0.0502		0.7622	0.0710
SD	0.0192	0.0303	0.7622		0.0415
T	0.4272	0.7441	0.0710	0.0415	

Table E62. ANOVA Statistics for Chl-*a* depth distribution, Site C (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	717.25	358.62	0.52	0.6010
Error	23	15845.11	688.91		
Corrected Total	25	16562.36			

Table E63. ANOVA Statistics for Chl-*a* depth distribution, Site D (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2560.77	1280.38	3.02	0.0869
Error	12	5094.99	424.58		
Corrected Total	14	7655.76			

E3.3. Statistics for diatoms, 2010

Table E64. ANOVA Statistics for diatoms depth distribution, Site A (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1.84	6.13	0.05	0.9835
Error	37	4.25	1.15		
Corrected Total	40	4.27			

Table E65. ANOVA Statistics for diatoms depth distribution, Site B (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	5.84	1.95	0.24	0.8690
Error	32	2.62	8.17		
Corrected Total	35	2.68			

Table E66. ANOVA Statistics for diatoms depth distribution, Site C (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	7.32	3.66	0.34	0.7123
Error	22	2.34	1.06		
Corrected Total	24	2.42			

Table E67. ANOVA Statistics for diatoms depth distribution, Site D (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1.3011495E19	6.5057475E18	0.80	0.4610
Error	22	1.7840285E20	8.1092204E18		
Corrected Total	24	1.9141434E20			

E3.4. Statistics for diatoms, 2011

Table E68. ANOVA Statistics for diatoms depth distribution, Site A (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	2.55	5.10	0.17	0.9684
Error	16	4.68	2.93		
Corrected Total	21	4.94			

Table E69. ANOVA Statistics for diatoms depth distribution, Site B (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	4.64	1.16	0.14	0.9646
Error	12	1.01	8.35		
Corrected Total	16	1.05			

Table E70. ANOVA Statistics for diatoms depth distribution, Site C (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	7.82	3.91	0.89	0.4381
Error	11	4.83	4.39		
Corrected Total	13	5.61			

Table E71. ANOVA Statistics for diatoms depth distribution, Site D (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	8.33	4.17	3.60	0.0626
Error	11	1.27	1.16		
Corrected Total	13	2.1			

E3.5. Statistics for dinoflagellates, 2010

Table E72. ANOVA Statistics for dinoflagellates depth distribution, Site A (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	4.08	1.36	0.37	0.7726
Error	34	1.24	3.65		
Corrected Total	37	1.28			

Table E73. ANOVA Statistics for dinoflagellates depth distribution, Site B (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	4.11	1.37	3.77	0.0217
Error	28	1.02	3.63		
Corrected Total	31	1.43			

Table E74. Tukey's (HSD) post hoc test, p-values for multiple comparisons of dinoflagellates sampling, Site B (2011)

depth(m)	1.5B	2SD	S	SD
1.5B		0.0027	0.3181	0.4230
2SD	0.0027		0.0214	0.0144
S	0.3181	0.0214		0.8403
SD	0.4230	0.0144	0.8403	

Table E75. ANOVA Statistics for dinoflagellates depth distribution, Site C (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1.36	6.73	1.18	0.3276
Error	21	1.21	5.71		
Corrected Total	23	1.33			

Table E76. ANOVA Statistics for dinoflagellates depth distribution, Site D (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1.52	7.64	0.11	0.8968
Error	20	1.39	6.97		
Corrected Total	22	1.41			

E3.6. Statistics for dinoflagellates, 2011

Table E77. ANOVA Statistics for dinoflagellates depth distribution, Site A (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	9.71	2.43	3.35	0.0340
Error	17	1.23	7.25		
Corrected Total	21	2.21			

Table E78. Tukey's (HSD) post hoc test, p-values for multiple comparisons of dinoflagellates between sampling depths, Site A (2011)

depth(m)	0.5B	1.5B	S	SD	T
0.5B		0.7526	0.0279	0.0275	0.6996
1.5B	0.7526		0.0378	0.0372	0.9509
S	0.0279	0.0378		0.9926	0.0329
SD	0.0275	0.0372	0.9926		0.0323
T	0.6996	0.9509	0.0329	0.0323	

Table E79. ANOVA Statistics for dinoflagellates depth distribution, Site B (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	5.15	1.29	0.82	0.5329
Error	13	2.03	1.56		
Corrected Total	17	2.55			

Table E80. ANOVA Statistics for dinoflagellates depth distribution, Site C (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1.61	8.01	1.20	0.3354
Error	12	8.02	6.68		
Corrected Total	14	9.62			

Table E81. ANOVA Statistics for dinoflagellates depth distribution, Site D (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1.39	6.98	0.89	0.4397
Error	11	8.66	7.87		
Corrected Total	13	1.01			

E3.7. Statistics for green algae, 2010

Table E82. ANOVA Statistics for green algae depth distribution, Site A (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1.53	5.12	1.14	0.3468
Error	36	1.62	4.49		
Corrected Total	39	1.77			

Table E83. ANOVA Statistics for green algae depth distribution, Site B (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	7.32	2.44	4.72	0.0077
Error	32	1.65	5.17		
Corrected Total	35	2.38			

Table E84. Tukey's (HSD) test, p-values for multiple comparisons of green algae between sampling depths, Site B (2010)

depth(m)	0.5B	1.5B	S	SD
0.5B		0.3004	0.0050	0.5469
1.5B	0.3004		0.0302	0.6119
S	0.0050	0.0302		0.0090
SD	0.5469	0.6119	0.0090	

Table E85. ANOVA Statistics for green algae depth distribution, Site C (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2.32	1.16	0.05	0.9493
Error	22	4.89	2.22		
Corrected Total	24	4.92			

Table E86. ANOVA Statistics for green algae depth distribution, Site D (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	8.48	4.24	0.38	0.6870
Error	22	2.44	1.12		
Corrected Total	24	2.53			

E3.8. Statistics for green algae, 2011

Table E87. ANOVA Statistics for green algae depth distribution, Site A (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	4.97	1.24	2.96	0.0501
Error	17	7.13	4.19		
Corrected Total	21	1.23			

Table E88. ANOVA Statistics for green algae depth distribution, Site B (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	6.23	2.07	0.29	0.8305
Error	14	9.96	7.11		
Corrected Total	17	1.06			

Table E89. ANOVA Statistics for green algae depth distribution, Site C (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	2.05	6.83	0.20	0.8956
Error	11	3.79	3.45		
Corrected Total	14	3.99			

Table E90 ANOVA Statistics for green algae depth distribution, Site D (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1.99	6.66	1.28	0.3301
Error	11	5.73	5.21		
Corrected Total	14	7.73			

E3.9. Statistics for Cyanobacteria, 2010

Table E91. ANOVA Statistics for Cyanobacteria depth distribution, Site A (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1.83	6.13	0.05	0.9835
Error	37	4.25	1.149		
Corrected Total	40	4.26			

Table E92. ANOVA Statistics for Cyanobacteria depth distribution, Site B (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	2.74	9.12	0.68	0.5711
Error	31	4.16	1.34		
Corrected Total	34	4.43			

Table E93. ANOVA Statistics for Cyanobacteria depth distribution, Site C (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1.29	6.45	1.79	0.1912
Error	22	7.95	3.61		
Corrected Total	24	9.24			

Table E94. ANOVA Statistics for Cyanobacteria depth distribution, Site D (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	.	1.47	7.39	0.09	0.9102
Error	22	1.72	7.82		
Corrected Total	24	1.73			

E3.10. Statistics for Cyanobacteria, 2011

Table E95. ANOVA Statistics for Cyanobacteria depth distribution, Site A (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	9.03	2.26	1.54	0.2342
Error	17	2.48	1.46		
Corrected Total	21	3.38			

Table E96. ANOVA Statistics for Cyanobacteria distribution, Site B (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	1.39	3.48	0.81	0.5405
Error	13	5.59	4.31		
Corrected Total	17	6.99			

Table E97. ANOVA Statistics for Cyanobacteria depth distribution, Site C (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	7.52	2.51	0.91	0.4676
Error	11	3.03	2.75		
Corrected Total	14	3.78			

Table E98. ANOVA Statistics for Cyanobacteria depth distribution, Site D (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1.63	5.43	1.40	0.2945
Error	11	4.26	3.87		
Corrected Total	14	5.89			

E3.11. Statistics for Cryptophyceae, 2010

Table E99. ANOVA Statistics for Cryptophyceae depth distribution, Site A (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1.71	5.70	0.47	0.7033
Error	37	4.46	1.21		
Corrected Total	40	4.64			

Table E100. ANOVA Statistics for Cryptophyceae depth distribution, Site B (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	3.82	1.27	0.74	0.5335
Error	31	5.29	1.71		
Corrected Total	34	5.68			

Table E101. ANOVA Statistics for Cryptophyceae depth distribution, Site C (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	3.57	1.78	0.58	0.5693
Error	22	6.79	3.085		
Corrected Total	24	7.14			

Table E102. ANOVA Statistics for Cryptophyceae distribution, Site D (2010)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2.68	1.34	0.72	0.4972
Error	21	3.89	1.85		
Corrected Total	23	4.16			

E3.12. Statistics for Cryptophyceae, 2011

Table E103. ANOVA Statistics for Cryptophyceae depth distribution, Site A (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	6.75	1.69	1.42	0.2770
Error	14	1.66	1.18		
Corrected Total	18	2.33			

Table E104. ANOVA Statistics for Cryptophyceae distribution, Site B (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	2.36	5.82	1.29	0.3266
Error	12	5.39	4.49		
Corrected Total	16	7.718			

Table E105 ANOVA Statistics for Cryptophyceae depth distribution, Site C (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	2.16	7.21	0.12	0.9454
Error	11	6.52	5.93		
Corrected Total	14	6.74			

Table E106. ANOVA Statistics for Cryptophyceae depth distribution, Site D (2011)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1.04	3.45	0.66	0.5959
Error	11	5.79	5.27		
Corrected Total	14	6.83			

E4. Statistics for comparison of data 2010 and 2011

E4.1. Nutrients

Table E107. Mann-Whitney Statistics for TDIN comparison 2010 and 2011, Site B

Wilcoxon Two-Sample Test	
Statistic	30.0000
Normal Approximation	
Z	2.3270
One-Sided Pr > Z	0.0100
Two-Sided Pr > |Z|	0.0200
t Approximation	
One-Sided Pr > Z	0.0242
Two-Sided Pr > |Z|	0.0484
Z includes a continuity correction of 0.5.	

Table E108. Mann-Whitney Statistics for SRP comparison 2010 and 2011, Site B

Wilcoxon Two-Sample Test	
Statistic	30.0000
Normal Approximation	
Z	2.3270
One-Sided Pr > Z	0.0100
Two-Sided Pr > |Z|	0.0200
t Approximation	
One-Sided Pr > Z	0.0242
Two-Sided Pr > |Z|	0.0484
Z includes a continuity correction of 0.5.	

E4.1. Phytoplankton

Table E109. Mann-Whitney Statistics for depth-weighted averaged Chl-*a* concentrations comparison 2010 and 2011, Site A.

Wilcoxon Two-Sample Test	
Statistic	29.0000
Normal Approximation	
Z	2.0821
One-Sided Pr > Z	0.0187
Two-Sided Pr > |Z|	0.0373
t Approximation	
One-Sided Pr > Z	0.0354
Two-Sided Pr > |Z|	0.0709
Z includes a continuity correction of 0.5.	

Table E110. Mann-Whitney Statistics for depth-weighted averaged diatoms biovolume comparison 2010 and 2011, Site A.

Wilcoxon Two-Sample Test	
Statistic	29.0000
Normal Approximation	
Z	2.0821
One-Sided Pr > Z	0.0187
Two-Sided Pr > |Z|	0.0373
t Approximation	
One-Sided Pr > Z	0.0354
Two-Sided Pr > |Z|	0.0709
Z includes a continuity correction of 0.5.	

Table E111. Mann-Whitney Statistics for depth-weighted averaged dinoflagellates biovolume comparison 2010 and 2011, Site A

Wilcoxon Two-Sample Test	
Statistic	29.0000
Normal Approximation	
Z	2.0821
One-Sided Pr > Z	0.0187
Two-Sided Pr > |Z|	0.0373
t Approximation	
One-Sided Pr > Z	0.0354
Two-Sided Pr > |Z|	0.0709
Z includes a continuity correction of 0.5.	

Table E112. Mann-Whitney Statistics for depth-weighted averaged green algae biovolume algae comparison 2010 and 2011, Site A

Wilcoxon Two-Sample Test	
Statistic	13.0000
Normal Approximation	
Z	-1.5922
One-Sided Pr < Z	0.0557
Two-Sided Pr > |Z|	0.1113
t Approximation	
One-Sided Pr < Z	0.0750
Two-Sided Pr > |Z|	0.1500
Z includes a continuity correction of 0.5.	

Table E113. Mann-Whitney Statistics for depth-weighted averaged Cyanobacterial biovolume comparison 2010 and 2011, Site A

Wilcoxon Two-Sample Test	
Statistic	13.0000
Normal Approximation	
Z	-1.5922
One-Sided Pr < Z	0.0557
Two-Sided Pr > |Z|	0.1113
t Approximation	
One-Sided Pr < Z	0.0750
Two-Sided Pr > |Z|	0.1500
Z includes a continuity correction of 0.5.	

Table E114. Mann-Whitney Statistics for depth-weighted averaged Cryptophyceae biovolume comparison 2010 and 2011, Site A

Wilcoxon Two-Sample Test	
Statistic	28.0000
Normal Approximation	
Z	1.8371
One-Sided Pr > Z	0.0331
Two-Sided Pr > |Z|	0.0662
t Approximation	
One-Sided Pr > Z	0.0518
Two-Sided Pr > |Z|	0.1035
Z includes a continuity correction of 0.5.	

Table E115. Mann-Whitney Statistics for depth-weighted averaged total phytoplankton biovolume comparison 2010 and 2011, Site A

Wilcoxon Two-Sample Test	
Statistic	30.0000
Normal Approximation	
Z	2.3270
One-Sided Pr < Z	0.0100
Two-Sided Pr > |Z|	0.0200
t Approximation	
One-Sided Pr < Z	0.0242
Two-Sided Pr > |Z|	0.0484
Z includes a continuity correction of 0.5.	

Table E116. Mann-Whitney Statistics for depth-weighted averaged total phytoplankton biovolume comparison 2010 and 2011, Site B

Wilcoxon Two-Sample Test	
Statistic	26.0000
Normal Approximation	
Z	1.3472
One-Sided Pr < Z	0.0890
Two-Sided Pr > |Z|	0.1779
t Approximation	
One-Sided Pr < Z	0.1074
Two-Sided Pr > |Z|	0.2148
Z includes a continuity correction of 0.5.	

Table E117. Mann-Whitney Statistics for depth-weighted averaged total phytoplankton biovolume comparison 2010 and 2011, Site C

Wilcoxon Two-Sample Test	
Statistic	18.0000
Normal Approximation	
Z	-0.3674
One-Sided Pr < Z	0.3567
Two-Sided Pr > |Z|	0.7133
t Approximation	
One-Sided Pr < Z	0.3614
Two-Sided Pr > |Z|	0.7228
Z includes a continuity correction of 0.5.	

Table E118. Mann-Whitney Statistics for depth-weighted averaged total phytoplankton biovolume comparison 2010 and 2011, Site D.

Wilcoxon Two-Sample Test	
Statistic	19.0000
Normal Approximation	
Z	-0.1225
One-Sided Pr < Z	0.4513
Two-Sided Pr > |Z|	0.9025
t Approximation	
One-Sided Pr < Z	0.4528
Two-Sided Pr > |Z|	0.9055
Z includes a continuity correction of 0.5.	